BOARDING AND ALIGHTING TIME OF PASSENGERS OF THE BERLIN PUBLIC TRANSPORT SYSTEM

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Abstract

The overall transportation speed is a significant factor influencing the attractiveness as well as the profitability of the transit system. If a vehicle needs less time to complete a tour, it can serve more tours and thus more passengers within the same time. Likewise, the passengers benefit from a decreased in-vehicle travel time. In this paper, the factors affecting the passenger transfer time are discussed for the case of Berlin, Germany. Furthermore, the paper presents the results of a survey that focuses (i) on the average time needed for passengers to board and alight a vehicle, (ii) its deviation, and (iii) the impact of the vehicle's occupancy and number of boarding/alighting passengers. Such data can also be used to model the boarding and alighting process at stops in transport simulations in a more realistic way. For buses and subways, more passengers standing in the door area of a vehicle are found to slow down the boarding and alighting process. The Berlin specific policy to allow the boarding of a bus only at the first door induces a significantly higher boarding time per passenger.

INTRODUCTION

The success of a transit system depends mainly on two factors (i) the system's attractiveness for the passengers of the demand side and (ii) the system's profitability for the operators of the supply side. The overall transportation speed is a significant factor influencing the attractiveness as well as the profitability of the system. If a vehicle needs less time to complete a tour, it can serve more tours and thus more passengers within the same time. Likewise, the passengers benefit from a decreased in-vehicle travel time. In cases where the vehicle speed cannot be further increased, e.g. because a speed limit applies, the dwell time needs to be shorten. Especially the time needed by the passenger to board or alight a vehicle at the stop can be optimized and lead to the desired effect (1, p. 1).

In this paper, the factors affecting passenger transfer time and the means of transportation will be discussed for the case of Berlin, Germany. The paper continues with the survey design and the results of the survey. The paper concludes with the discussion of the results. The focus of the survey lies (i) on the average time needed for passengers to board and alight, (ii) its deviation, and (iii) the impact of the vehicle's occupancy and number of boarding/alighting passengers. These figures enable transport modelers to model the boarding and alighting process at stops in a more realistic way (e.g. 2, 3).

FACTORS INFLUENCING THE PASSENGER TRANSFER TIME

The passenger transfer time starts when the first passenger steps into the public transport and ends when last alighting passenger left the vehicle. This time includes both, the boarding and alighting time and can be divided into these two segments. Overall this period of time defines the largest proportion of the dwell time at a stop and is of great importance.

The passenger transfer time is affected by many factors in a positive or negative way. This paper only concentrates on the main influencing factors like the behavior of the passengers itself, the occupancy of the vehicle and the design of the vehicles and the stops.

Ticket purchase

The opportunity to buy and devaluate a ticket on-board a transit vehicle may block the entrance area and thus increase the passenger transfer time. A high rate of permanent tickets or the positioning of ticket vending machines outside the vehicles, i.e. at the stop (1, p. 7), reduces this effect. This is an important issue for buses operated by Berlin's public transit authority BVG. These buses provide in-vehicle ticket purchases and devaluations while operating under a first-door-entry-only policy. That is, whenever a passenger buys or devaluates a ticket it blocks the sole entrance.

Passenger information

In-vehicle information systems can announce the upcoming stops and times of arrival. Thus, the passenger is able to prepare for the arrival, e.g. proceeding to the door, well in advance. Furthermore, such an information system may reduce the number of requests to the driver (1, p. 7).

Number and attributes of passengers

For a given design of a vehicle, more boarding and alighting passengers translate directly into more interactions among the passengers. Consequently, the passengers may block each other and are hindered to get to the doors. Each passenger needs more time to board or alight and the dwell time increases. The same holds true if passengers can board and alight simultaneously at the same

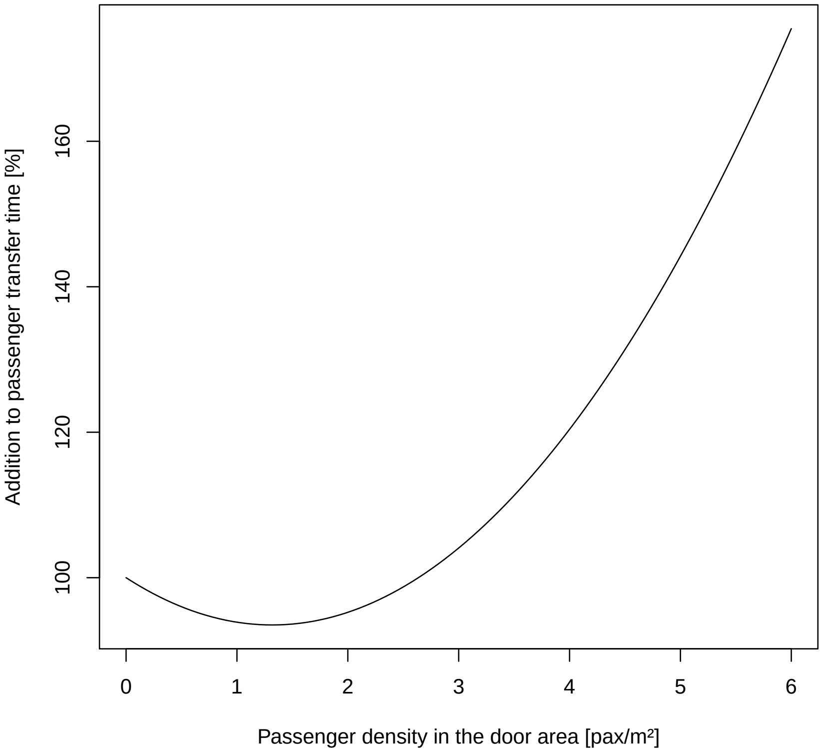


FIGURE 1 passenger transfer time depending on occupancy, based on (4, p. 58)

door (1, p. 8).

A further increase of the boarding/alighting time derives from personal attributes of the passenger, i.e. sex, age, and mobility restrictions. The mobility of people can be restricted by baggage, stroller, bike, age or disabilities (1, p. 8).

Vehicle occupancy

As illustrated in Figure 1, the time needed for each passenger to board or alight increases with the number of passengers standing in the door area for densities of more than 1.5 pax per m^2. Observations conducted in this survey indicate that the opposite may be the case, i.e. passengers that wish to alight occupy the door area and alight as one homogeneous group. In this case, the transfer time decreases. The transfer time may also increase in case a vehicle reaches about 2/3 of its capacity (4, p. 58).

Vehicle design

In the following, a brief overview is provided outlining a range of design decisions that influence the passenger transfer time. Note that not all features are present for all types of vehicles.

Kneeling

A vehicle equipped with kneeling has the property to allow passengers a level access and exit. If the vehicle does not have kneeling, the stops/stations can be modified to make a level access possible. In general, providing a level access/exit facilitates the transfer especially for disabled people and reduces the time needed to board or alight (1, p. 3). In Berlin, only buses are equipped with kneeling. The remaining vehicles (mostly trains and trams) revert to modified platforms for level access.

Number and width of doors

In general, doors represent a bottleneck for the passenger when boarding or alighting. Nevertheless, the impact of the door width on the transfer time is controversial. In his studies, Weidmann has shown that the door efficiency rises linear with the door width until the door has reached a width of 1.5 m. For broader doors, the efficiency slightly decreases because they are not fully used up to their capacity. Furthermore, substituting a few broad doors by smaller doors with the same total width allows for more passengers to transfer at the same time, see e.g. (1, p. 3) and (4, p. 60).

Distribution of doors

The transfer time can further be decrease by (i) distributing the doors uniformly along the vehicle, (ii) decreasing the distance between doors, e.g. by adding more smaller doors that allow passengers to reach the doors faster, and (iii) coordinating the doors of the vehicle with the access points of the stopping facility, i.e. a platform with a sole access at one of its ends hinders the passengers from using the whole length of the vehicle (1, p. 4).

Flow capacity

The aisle width and the positioning of the luggage compartment both influence the in-vehicle flow capacity of the passengers and thus the transfer time. The luggage compartment, normally reserved for luggage, strollers, and wheelchairs, is often occupied by passengers who do not want to alight immediately. Since these passengers slow down boarding and alighting passengers in a similar way as passengers standing in the entrance area the luggage compartment and aisles should be kept clear. Last, stairs have a negative impact on the in-vehicle flow capacity.

Station design

Level entry and gap width

As stated earlier, providing a level entry has a positive effect on the transfer time. If this cannot be achieved by the kneeling of the vehicle the platform may be modified. A height difference of 10 cm is considered the maximum to allow people in wheelchairs to access the vehicle independently (1, p. 5). Likewise, a gap between platform and train of more than 15 cm forms an insurmountable obstacle and a gap of 5 cm have been proved as acceptable (1, p. 5). In general, a gap of more than 20 cm increases the transfer time by about 18 % (4, p. 63). Combinations of gap and height difference might impede the usage of the vehicle even if none of the two alone exceeds the aformentioned values (4, p. 63).

Distribution of passengers

The accessibility of the station affects the distribution of passengers and therefore has influence on the transfer time. A single access at the beginning or the end of a station or stop causes an unsymmetrical distribution of the waiting passengers. Furthermore, a minimum width of the platform should not be undercut so that passengers can freely distribute at the platform (1, p. 6).

PUBLIC TRANSPORT IN BERLIN

The following section introduces the different vehicle types of the the transit modes of Berlin. Namely these are *bus*, *tram*, *U-Bahn* (subway), *S-Bahn* (inner urban commuter rail service similar to U-Bahn), and *Regio* (regional trains). Ferries are left out due to being insignificant in terms of ridership.

In Berlin, there are 4 different types of *bus* that can be classified into *double-decker bus*, *articulated bus*, *biaxial bus*, and *triaxial bus* (5). The *double-decker* has two floors and 3 doors distributed over a length of 13.70 m, a width of 2.55 m, and a height of 4.06 m. The second floor can be reached over stairs in the front and the back of the vehicle. On the main deck the *double-decker* offers 28 seats and on the upper deck 55 seats. In addition, it provides standing room for 45 passengers. Most of the *articulated buses* have also 3 doors but these are distributed over a vehicle length of 18 m. There also exists a design with 4 doors. It offers between 44 and 55 seats and up to 132 standing places. The *biaxial bus* with 2 or 3 doors features 26 to 38 seats and a standing room for up to 75 passengers at a length of about 12 m. The *triaxial bus* with 2 or 3 doors provides up to 42 seats and a standing room for 111 passengers. Its length is about 15 m.

The vehicles of the *tram* system can be divided into two different types, the high floor tram *kt4d*, and the low floor trams *gt6* and *flexity* (5). The *kt4d* vehicles offer 33 seats and a standing room for 66 passengers per wagon. The floor height is 90 cm above ground and the wagon is accessed by steps. The *gt6* offers 45 to 58 seats and a standing room for 95 to 103 passengers per wagon. The floor height of only 30 cm provides level entry access at the stops. The *flexity* has the same floor height as the *gt6* but features an increased capacity of 52 to 84 seats and a standing room for 132 to 173 passengers per wagon. Since the delivery of the *flexity* is not complete yet, they were only underrepresented in the survey and thus not analyzed.

The *U-Bahn* trains come in two different sizes. The *large profile* trains of the *F-series* and *H-series*, and the *small profile* trains of the *HK-series*, *A3-series*, and *GI-series* (5). The *large profile* trains consist of 4 or 6 wagons. Each wagon of the *F-series* has 3 doors with a width of 1.20 m and offers 36 to 38 seats and a standing room for 79 to 89 passengers. The *H-series* instead has 3 doors with 1.34 m width and provides 52 seats and a standing room for 96 passengers. In contrast to the *large profile* trains, the *small profile* trains consist of 2, 4, 6 or 8 wagons. The *HK-series* and the *A3-series* have 3 doors per wagon each and a door width of 1.34 m (*HK*) and 0.94 m (*A3*). *GI*-wagons only have two doors with a width of 1.20 m. *HK* trains feature the least number of seats per wagon (19). The *A3* provides 26 and the *GI* 32 seats per wagon. Comparing the standing places, *HK* provides 81, *GI* 63 and *A3* 52 seats per wagon.

There are three different types of *S-Bahn* trains in Berlin, *BR 480*, *BR 481/482*, and *BR 485* (6, 7). The types of *BR 481* and *BR 482* form permanently coupled two car electric multiple units and are thus both included as *BR 481* in the survey. Except for the *BR 485*, the two other trains have 6 doors per wagon (3 on each side of the wagon). The *BR 485* itself has 8 doors per wagon. All types consist of two wagon units with minor differences between the two wagons concerning the capacity. Each wagon of the *BR 480* and *BR 481* has a capacity of 44 or 50 seats and a standing room for 94 to 106 passengers, i.e. 4 passengers per square meter. The *BR 485* provides 44 or 56 seats per wagon and a standing room for 253 passengers per two wagon unit, i.e. 5 passengers per square meter. Trains consist of 2, 4, 6 or 8 wagons.

This survey only concentrated on one *Regio* vehicle type, the so called *dbpza* train (8). Each wagon provides 2 floors and 2 doors on the lower floor with an average width of 1.30 m. Since the in-vehicle design varies from wagon to wagon the capacity varies from 68 to 118 seats with a standing room of 105 to 130 passengers. The number of wagons per train is adapted to the demand and the route the train is operated on. With new operators entering the local market more vehicle designs start appearing. However, these are still underrepresented in the survey and thus not analyzed.

DESIGN OF THE SURVEY

The goal of the study is to determine the average boarding and alighting time per passenger for public transport in Berlin. In this process, the dependence of boarding and alighting time on occupancy is analyzed as well.

For this survey, the boarding time starts as soon as the first passenger steps into the vehicle and ends when the last passenger has boarded the vehicle. The alighting time starts as soon as the first passenger steps out of the vehicle and ends once the last passenger has left the vehicle. If passengers disembark only to make room for other passengers to alight, the alighting time ends when the last of these passengers steps back into the vehicle. Such passengers are neither counted as boarding nor as alighting passengers.

If passengers start boarding while some other passengers still alight, the alighting time stops once more passengers enter the vehicle than leave it. The boarding time starts immediately after the alighting time has stopped. To avoid a falsification of the data, a 3-second rule has been introduced. If more than three seconds pass without someone boarding or alighting the boarding/alighting time stops. All “latecomers” are excluded from the measurement. Furthermore, the number of boarding and alighting passengers is counted for the boarding and alighting time respectively. All passengers are counted, except for infants carried in a stroller or by their parents. A stroller, wheelchair or other special cases (bad access and exit conditions, height difference, etc.) are noted separately.

If possible, all doors of a vehicle are included in the survey with separate measurements for each door of this vehicle. The measured vehicle is selected with respect to the number of passengers, i.e. a higher occupancy is favored, and the layout of the vehicle, i.e. vehicles of the *Regio* train with bicycle compartments or dining facilities are not considered.

During the arrival of the vehicle, the occupancy is estimated. For the first surveys, which took place in 2010 and 2011, the occupancy was estimated in percent. The students who made the measurements were advised to use categories in 25 % steps as defined by Table 1. These 25 % steps were later found to be misleading, as e.g. an occupancy of 50 % is usually not equal to many seats occupied and few passengers standing because public transport vehicles often have much more standing room than seats. That is why the new occupancy categories labeled low, medium and high were introduced in 2013, which are based on the categories used before. However, the new categories concentrate on the number of passengers in the door area as these passengers obstruct boarding and alighting most, see Table 2 for the definition. The old categories of $\leq$25 % and $\leq$50 % show both up as low occupancy in the results whereas $\leq$75 % and $\leq$100 % are mapped to medium and high occupancy respectively.

Survey Implementation

Since 2010, the survey is repeated each year during the summer term, i.e. May and June. To include the rush hour, all measurements have been arranged on weekdays (Monday to Friday) between 7

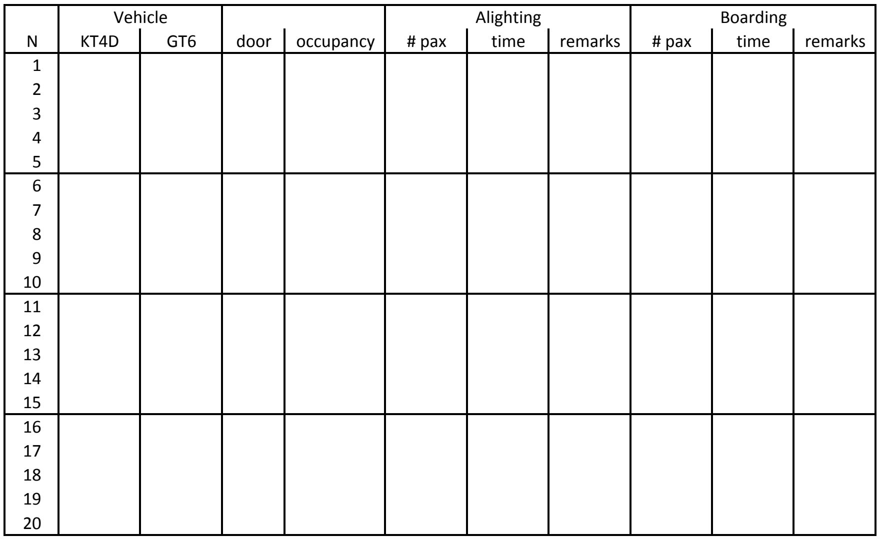
TABLE 1 Definition of vehicle occupancy for the years 2010 and 2011

Occupancy	Definition
$\leq 25\,\%$	Some seats occupied, no/a few passengers standing
$\leq 50\,\%$	Many seats occupied, no/a few passengers standing
$\leq 75\,\%$	Many seats occupied, passengers standing in the door area
$\leq 100\,\%$	Many seats occupied, many passengers standing in the door area and in the aisles

TABLE 2 Definition of vehicle occupancy for the years 2012 and later

Occupancy	Definition
low	No/a few passengers standing
medium	Passengers standing in the door area
high	Many passengers standing in the door area and in the aisles

TABLE 3 Example survey questionnaire for tram



	Vehicle				Alighting			Boarding		
N	KT4D	GT6	door	occupancy	# pax	time	remarks	# pax	time	remarks
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
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16										
17										
18										
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20										

and 10 o'clock or between 16 and 20 o'clock.

The survey was carried out by the Bachelor students of the module "Basic principles of transport systems planning and transport informatics" at the Technische Universität Berlin. Thus, the whole survey has been subdivided into many smaller surveys at many different stations in Berlin representing individual teams of the different tutorials of the module. Each team had to develop its own questionnaire, which had (at least) to include the information shown in the *tram* example of Table 3. The collected raw data was merged and edited by the authors who also took responsibility for the coordination of the survey.

Each team developed its own measuring process, but had to obey the aforementioned definitions of e.g. the boarding time. Usually each student measured a single door. Whereas most groups used stopwatches and mobile phones to measure times, some groups relied on self-written applications and video recordings. The latter allowed to analyze the boarding and alighting process at a later stage without time pressure. This proved to reduce the measurement errors but raised privacy issues. Thus, only footage of the passengers' feet was allowed. The measurements with stopwatches and mobile phones are more error-prone because the students had to count the boarding and alighting passengers while simultaneously measuring the boarding and alighting times. Personal experience from the authors showed that differences of up to 10 % between boarding passenger counts of two students (the same door and the same arrival) are common.

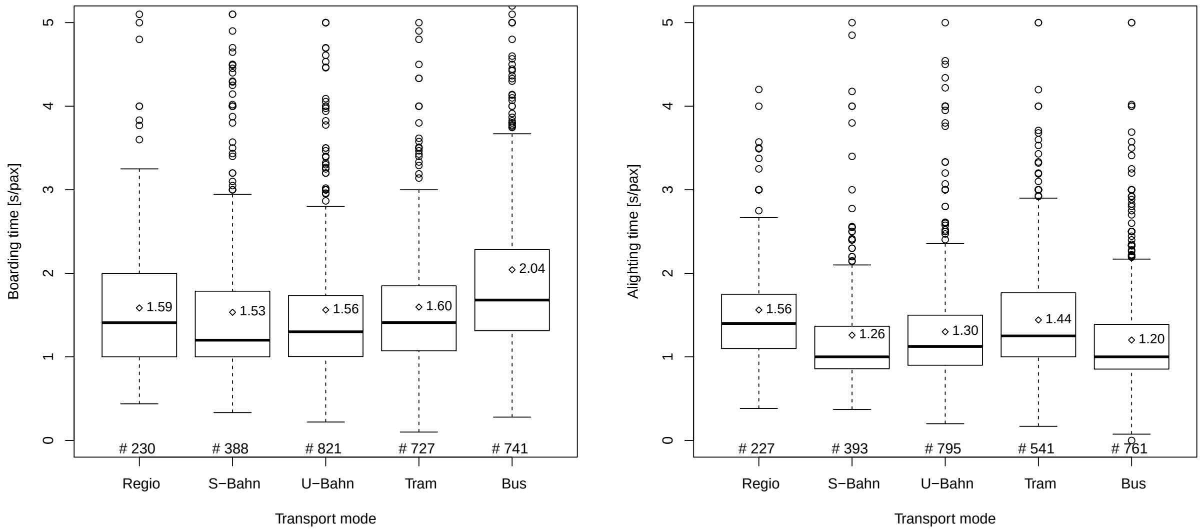
RESULTS

From 2035 vehicle observations, 2717 alighting and 2907 boarding events for individual doors were analyzed. Under negligence of specifics like bikes, stroller, wheel chairs, etc., the data set still contains 2458 and 2499 door observations for alighting and boarding passengers respectively. The data had been collected in 2010, 2011, 2012, and 2013. Data of the year 2014 is currently in post-processing.

General results

Figure 2 features the data of boarding and alighting time for all public transport modes covered in this survey. Comparing boarding and alighting time shows higher values for boarding passengers for all modes except for *Regio* trains. Rolling stock of the *Regio* system does not offer a level exit at all stations. Instead, passengers need to step down while boarding a vehicle and go upstairs when alighting. Consequently, alighting and boarding needs the same amount of time, i.e. a potential lower alighting time is compensated by the non-level-entry. *Buses* show the lowest alighting time of all modes. However, the boarding time is the highest one of all modes indicating that the first-door-entry-only policy applied in Berlin is not the best practice.

Figure 3 shows the boarding time of all types of public transport covered by this survey. The *S-Bahn* vehicles of the type 485 were only measured 7 times and are thus not included in this plot. The mean ranges from 1.49 to 2.21 seconds per passenger. The difference between alighting and boarding time is the highest for *buses*; for the rest the variation is not as large. With the exception of the *Regio* vehicles (dbpza), the boarding time exceeds the alighting time. The alighting time is almost equal for all transportation modes with *buses* having a somewhat smaller average alighting time than the other modes. The modern level-entry *gt6 tram* vehicles show slightly improved boarding/alighting times compared to the older *kt4d*. In fact, the *gt6* is on a par with *S-Bahn* and *U-Bahn*. Further analysis of the data indicates that specifics like bicycles or a ticket purchase only slightly increase the average boarding time, i.e. the time needed per passengers increases by 0.01



(a) Boarding time per passenger - box plot with arithmetic mean and sample size

(b) Alighting time per passenger - box plot with arithmetic mean and sample size

FIGURE 2 Distribution of boarding and alighting time of all public transport modes including specifics - Outliers greater than 5 not shown here

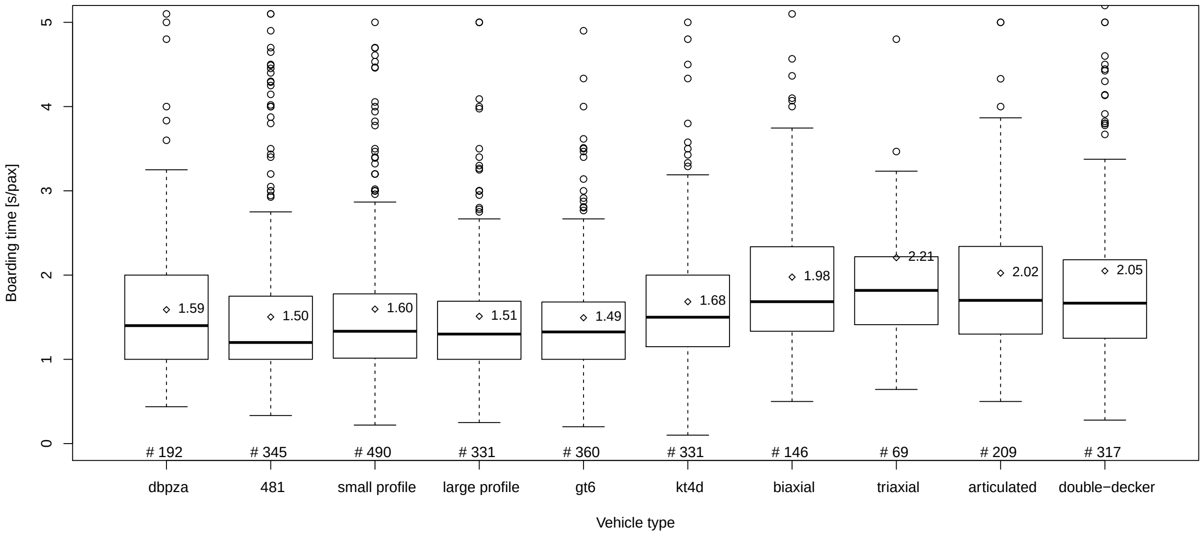
to 0.11 s.

The analysis of the survey data shows a linear relationship between the number of boarding or alighting passengers and the time needed to board or alight. The scatter plots in Figure 4 illustrate this relationship for all vehicle types of the survey.

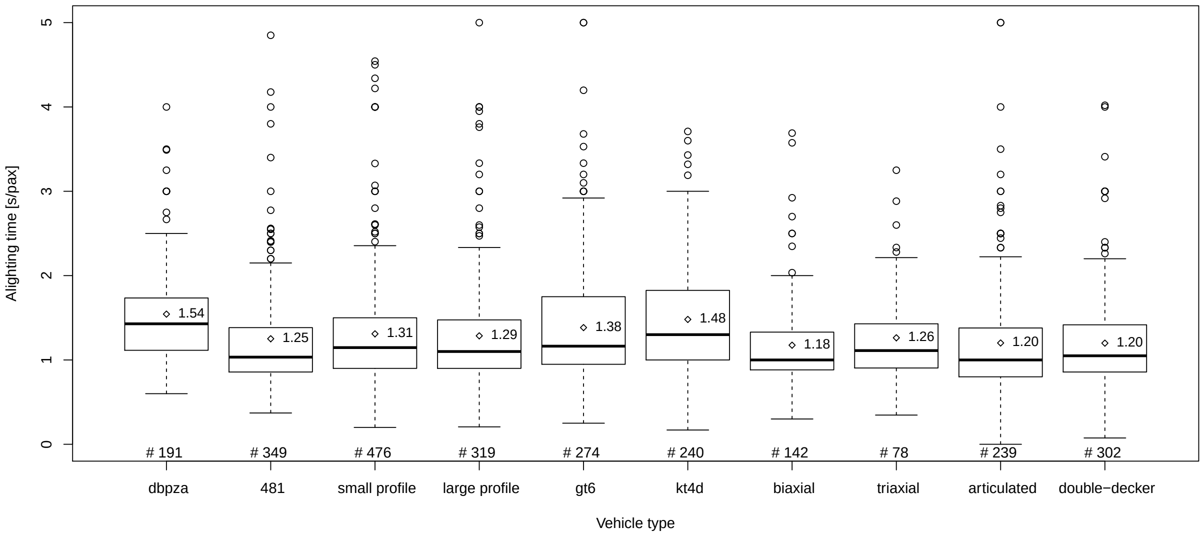
The impact of the vehicle occupancy

The boarding time for *buses* increases linearly as the level of occupancy rises from low to high. The total increase of the average accounts for 0.64 seconds per boarding passenger, see Figure 5. This considerable large increase is not only induced by a higher number of interactions between passengers but also by some indecisive passengers that e.g. search for an empty seat. When boarding a *double-decker*, passengers have to decide immediately whether to go upstairs or to stay downstairs. While pondering they block the sole entry of the bus. Compared to the average the median only increases by 0.05 seconds. This indicates that the increase of the mean can be attributed to more frequent outliers.

The alighting time for *buses* increases only slightly with the level of occupancy, i.e. by 0.11 seconds from low to high occupation. This effect can be attributed to passengers preparing to alight well in advance, which might counterbalance the effects mentioned for boarding. In-vehicle announcements of the upcoming stops support a suitable preparation of the passenger. In addition, there is the intrinsic motivation of the passenger's fear not to get out in time, i.e. being forced to travel one stop further. Contrarily, in a low-occupancy environment, passengers can better estimate the time needed to reach the door and are thus more relaxed.



(a) Boarding time per passenger - box plot with arithmetic mean and sample size



(b) Alighting time per passenger - box plot with arithmetic mean and sample size

FIGURE 3 Distribution of boarding and alighting time of all public transport vehicles - Outliers greater than 5 not shown here, S-Bahn vehicle type 485 not included due to a sample size of 7

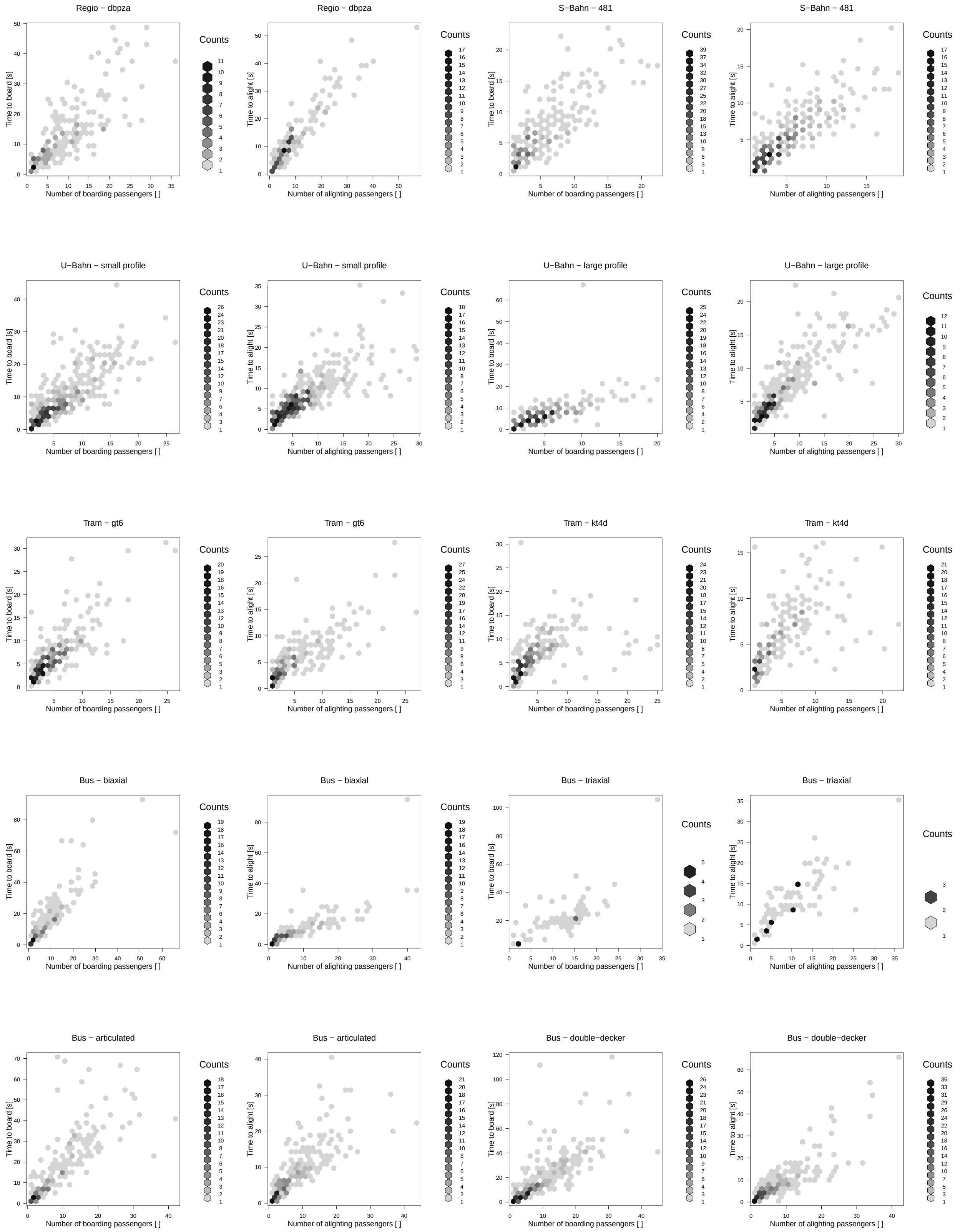


FIGURE 4 Distribution of boarding and alighting time of all public transport vehicles - S-Bahn vehicle type 485 not included due to a sample size of 7

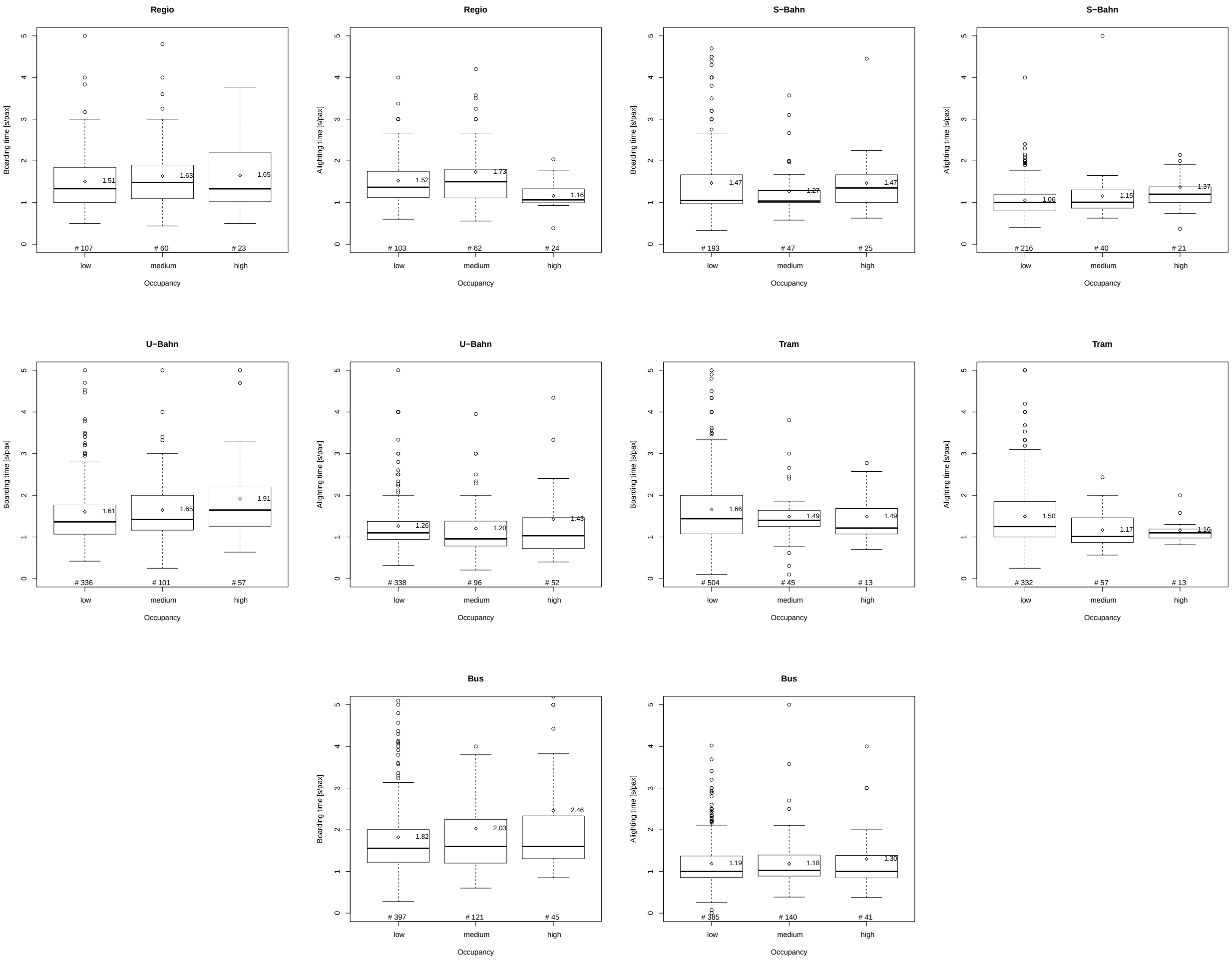


FIGURE 5 Boarding and alighting time of transport modes depending on occupancy

The vehicles of the *U-Bahn* follow the same general pattern as the *buses*. Again, more interactions between passengers increase the average time by 0.30 seconds per boarding passenger for a level of high occupancy compared to low occupancy. Analyzing the alighting time, the pattern is different. First, there is slight decrease of 0.06 seconds per alighting passenger from low to medium occupancy. This is followed by an increase of 0.23 seconds for high occupancy levels. Although the median is more robust to outliers, it follows the same trend. A possible explanation is that reaching the door area before the train stops becomes more difficult for highly occupied vehicles. The consequences are again a rise of interactions and thus time needed for each passenger. The findings of Weidmann in Figure 1 support this. This assumes 4-5 passengers per square meter being equivalent to high occupancy.

The sample size for medium and high occupancy levels for vehicles of the *S-Bahn* system is much lower compared to the *U-Bahn*. Only data for the low occupancy level is considered to be representative. The vehicles of the *S-Bahn* show significantly lower boarding and alighting times than the ones of the *U-Bahn* despite the numerous similarities between both designs.The alighting time shows a continuous increase in time (average and median) in relation to occupancy. This trend is different from the trends of the other rail-based vehicle types, but may be attributed to the low number of measurements.

The number of measurements for the *Regio* is rather low. Thus it may be biased by the location and time of the measurement. The results differ from the other transit modes as boarding time and alighting time both peak at medium occupancy.

Most of the measurements for the *tram* are categorized as low occupancy. Data for medium and high occupancy is considered less reliable due to the smaller samples. Note that the alighting time for *tram* vehicles of low occupancy is much higher than for *buses* of the same category. The reason is unclear but may be related to conflicting passenger streams in the *tram* system, i.e. the first-door-entry-only policy of the *buses* prevents alighting passengers to become blocked by boarding passengers.

The influence of the first-door-entry-only policy

The Berlin specific policy to allow boarding of *buses* only at the first door is considered inefficient with respect to the passenger boarding time. Figure 3(a) indicates that except for the *triaxial bus* the boarding time is about the same for all types of vehicles. The slightly larger 2.21 seconds of the *triaxial bus* is a direct result of some severe outliers combined with a smaller sample. Since all buses are subject to the same policy there is no comparison data. Instead, the *buses* are compared to the level-entry *gt6 tram* vehicles. Note that the *gt6* features a similar design but offers four doors instead of the two or three doors of the *buses*. For the comparison, measurements of the the first door only are taken into account. The comparison of *buses* and *gt6* in Figure 6 reveals a significant higher boarding time for *buses*. This is supported by the time distribution in Figure 4 whose linear regression's gradient is nearly doubled for the *buses*.

CONCLUSION AND OUTLOOK

The data of the survey can be used to model the boarding and alighting process at stops in a more realistic way. In general, the data for *buses* and *U-Bahn* supports the findings of Weidmann. More passengers standing in the door area translate directly slower boardings and alightings. The Berlin specific policy to allow boarding of *buses* only at the first door induces a significantly higher boarding time per passenger. Further studies are scheduled for summer 2015. Especially the impact

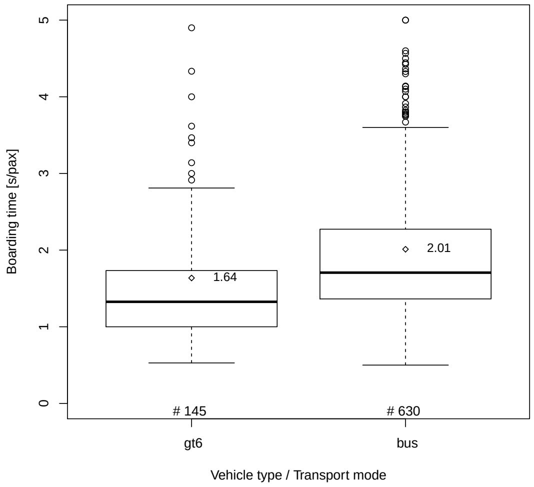


FIGURE 6 Comparison of boarding time of tram type *gt6* and buses - First door only

of occupancy needs to be researched in more detail. The coaching of the students carrying out the study will be more standardized.

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