Measuring the distribution of the punctuality for passengers on a train journey with zero or more transfers

Author: Wouter den Duijn
Supervisor: Dr. Bram Gorissen

Vrije Universiteit Amsterdam

Abstract. The punctuality for passengers is defined as the percentage of successful train journeys. A journey is successful if the passenger reaches its final train station with a delay less than 5 minutes. This punctuality for passengers tries to capture all the possible delays in a train journey, including any transfers. However, this number does not gives us insight how the connections perform on an individual passenger level. From the actual departure and arrival times we computed planned and actual transfer times to investigate the efficiency of a connection on Utrecht Central Station. We show that the transfer punctuality is 83.86% at Utrecht Central Station. Next to this, if a passenger is delayed, he is unable to catch its desired connecting train in 57.9% of the cases. The results demonstrate the added value of reporting the actual distribution of the delay of a transfer instead of the percentage of delayed passengers. This can have an significant effect on the total travelling time of the passenger and the overall customer satisfaction.

Keywords: Train punctuality Punctuality for passengers Transfer times Dutch Railways

1 Introduction

Utrecht Central Station has approximately 240,000 people using this station on average each day [1]. This number includes single train journeys and transfers. Due to unreliability of trains not all these transfers will be successful. Missing your connection can have a significant impact on the the continuation of the journey. On the contrary, due to variance in arrival times, in some cases a passenger might be able to reduce his total travelling time. For example, a passenger might be able to catch the train which is planned too early for the connection, but due to a delay this connection is possible.This can result in an arrival time at the final station before the planned arrival time.

Initially, The Dutch Railways, NS, reported on the train punctuality. Train punctuality is the percentage of trains which arrive with a delay less than 5 minutes. This number has been criticized by a report of the Ministry of Infrastructure and Environment [8]. This report states that the number of passengers per train should be taken into account. Also, the cancelling of trains and possible connecting passengers should be included in the computation of the reliability of the rail network. Therefore, since 2012 the NS also reports on the punctuality for passengers [3]. This punctuality for passengers indicates the percentage of successful train journeys. This implies that the train did actually execute the planned journey, the final train station has been reached within 5 minutes of the planned arrival times, including any transfers.

Furthermore, this report of the Ministry of Infrastructure and Environment reported about the reliability and robustness of the dutch railways [8]. The report focuses on a wider perspective of reliability, thus not solely focusing on travelling times. Also, this report states the importance of bearing in mind cancelled trains for delayed journeys. However, this release does not perform any computation on individual train level, but reports on high level general metrics of the dutch railways.

Numerous studies attempted to improve the railway train tables for the sake of optimizing the railways and also providing more reliable connections [2, **?**]. These studies focus on a general improvement of the train table and do not go in depth about the reliability of the current train table.

While all of the above studies and publications do touch the subject of the punctuality of passengers, they also have their shortcomings. No study does go in depth into this punctuality for passengers. The NS reported that the punctuality for passengers in 2016 is 91.3%. Lots of people still are not satisfied with the current train table and its reliability [6]. Therefore, this paper focuses on the distribution of the punctuality for passengers. This could benefit to new insights by looking on an individual passenger level. We focus on transfers at Utrecht Central Station, as this is an important junction in the dutch rail network.

This paper is organized as follows: First, we treat our methodology and data preparation in 2. Thereafter, the results are presented in Section 3. Finally we draw conclusions in Section 5.

2 Methodology

This section describes the methodologies used in this study. This section mainly consist of two parts: the process and the data preparation.The process will consist of the retrieving of the arrival and departure times at Utrecht Central Station, the matching to the schedule and the planned versus actual transfer time computation. The data preparation will discuss the available resources and the data preparation.

2.1 Process

Trip and series number definition Before we continue to treat our methodology we will define a trip. A trip is defined as a train with a begin and

end station plus the departure time. A trip can only be executed once each day. A trip code with a date uniquely identifies a trip. For example, trip code 3069 represents the train from Den Helder to Nijmegen departing at 17:34.
A series number is a number to represent a collection of trips. This series number is a multiple of hundred and represents a route in the train table independent of departure time or direction. A trip code is a member of the series if: *series number* < *trip code* < (*series number* +100). All odd trip codes in a series are heading the same direction and the even trip codes are heading the opposite direction. Extending the above example, all odd trip codes in series 3000 will head to Nijmegen and all even trip codes in series 3000 will head to Den Helder.

Match to train table The data set of the NS contains train times and locations of all the NS routes in the Netherlands. We are only interested in transfers on Utrecht Central Station. Therefore, we removed trains from our data set which are not present in the train schedule of Utrecht Central Station. After this step, we matched each trip to the train schedule based on the trip code.

Departure and arrival time computation For each trip we determined whether an observation is a stop at Utrecht Central Station. An arrival is defined as the first observation of the trip that represent a stop at Utrecht Central Station. The same goes for a departure, only now for the last observation.
After the generation of the departure and arrival times, we point out that the trips starting or ending at Utrecht Central Station have many missing observations near the station. For the sake of keeping these trips, we will estimate the remaining travelling time of this train from or to Utrecht Central station. We generated a scatter plot of the remaining travelling distance against the remaining travelling time stratified per series. From this data we can estimate the departure and arrival time given the last known location. In this scatter plot we see lots of variance. Thus, we do not have an accurate estimator. Therefore, we defined three scenarios: optimistic, median and pessimistic. The remaining travelling time for these three scenarios use respectively the 10%, 50% and 90% quantile.

Planned versus actual transfer time Each arrival at Utrecht can have multiple connections, depending on the direction. For each potential connection we computed planned and expected transfer times. In algorithm 1 a high level overview of this process is defined. We set the minimum transfer time $M = 5$ minutes as Utrecht Central Station is a big station with many platforms. The algorithm uses a matrix Cm which contain info for valid connections. A valid connection is determined using the NS reisplanner [5]. Thus giving an arriving direction and heading direction, is Utrecht Central Station a station where a transfer should be made? Sometimes this can result in a different actual departing train than the planned train. Possibly, this actual departing train is from a different series than the planned train. Therefore, we check if the two departing trains are the same type of train (sprinter or intercity).

Transfer punctuality From these computations we derived a new metric, the transfer delay. This transfer delay is defined as: *planned departure time − actual departure time*. Where the departure is the departure at Utrecht Central Station when transferring. The transfer punctuality is the percentage of connections that has a transfer delay of less than 5 minutes. This metric gives us insight in the efficiency of the connection.

Algorithm 1 Determine the planned and actual transfer times of an arrival

Input: P: planned arrival time
A: actual arrival time
D: direction arriving from
Ds: list of all directions from Utrecht Central Station
Cm: matrix containing whether two directions are valid connection
M: minimum transfer time at Utrecht Central Station

Output: L_p: list of planned transfer times
L_a: list of actual transfer times

```
L_p, L_a ← empty list
for d in Ds do
  if Cm(D, d) = true then
    p ← first planned departure time after time P + M heading to d
    a ← first actual departure time after time A + M heading to d with the same
    type train
    L_p.insert(p).
    L_a.insert(a).
  end if
end for
return L_p, L_a
```

Where the same type of train means that the planned and actual train are both an intercity or both a sprinter.

2.2 Data Description and preparation

For this study, NS train GPS coordinates from a publicly available data source in the period: 10 May 2017 – 20 June 2017 were made available. Each trip contains an observation every 20 seconds. The total number of observations in this data set equals 52,307,749. These observations contain 5 columns:

- **Seconds:** an integer displaying the UNIX time of the observation [10].
- **Route:** a number indicating the route of the observation.
- **Vehicle:** a string displaying the vehicle number. The vehicle number does not correspond to a physical train, but contains the trip code.
- **Latitude:** a real number indicating the latitude.
- **Longitude:** a real number indicating the longitude.

The route is not of any value to this research as the trip code has all the information about the trip to match this to the train table. As for the seconds column we will convert this to a date time struct. Next to the above data, we imported the (manually computed) train table of the NS containing the scheduled departure and arrival times at Utrecht Central Station. The following columns are specified:

- **Direction:** a string stating the direction where it is heading (departure) or arriving from (arrival).
- **Series number:** a number showing the series number.
- **Minutes:** an integer displaying the minute of the hour the event occurs.
- **Head Station:** a boolean that is true if Utrecht Central Station is the begin or end station of this trip. False otherwise.
- **Odd:** a boolean that is true if the trip code is odd. False if trip code is even.
- **Double frequency:** a boolean that is true if the trip executes a two per hour frequency. False if this trip is made once per hour.
- **Arrival:** a boolean that is true if it is an arrival. False if it is a departure.

Segregating data per trip As the original data feed is sorted on time, each specific trip is spread out around the data set. To group the data set by trip we will sort the data set on vehicle number and seconds (ascending). This way, each trip can be handled separately in a chronological order.

Expanding data set with speed, stations and stop From the above mentioned structure, the current speed and station and stop indicator can be retrieved. The speed (km/h) at each observation is computed as following:

$$speed(i) = 3.6 \cdot \frac{distance(i, i+1) + distance(i-1, i)}{seconds(i+1) - seconds(i-1)} \tag{1}$$

Where i corresponds to the ith observation in the trip. The $distance(x, y)$ is the great-circle distance between coordinate x and y in meters.

We assume a train has stopped at Utrecht Central Station when its velocity is less than 5 km/h and the distance to the center point of Utrecht Central Station is less than 300 meters.

3 Results

This section present the results of the matching to the schedule, the missing observations distribution, the statistics of delayed arrivals plus the transfer delays.

3.1 Matching to schedule

The matching to the schedule has not been successful for each planned departure or arrival. In Table 1 we can see the percentage of matches per series number. The overall percentage of matched departures/arrivals is 73.5%. The percentage of matched departures and arrivals is equal for many series numbers. This is because these trips do not start or end at Utrecht Central Station. Thus if an arrival is present in the data, the departure is also available. Also, we notice from Table 1 that series number 5500 has a tiny percentage of its schedule matched. The 5500 series is the route between Utrecht Central Station and Baarn. As there was no clarification of this missing data, we will disregard series number 5500 for future process.

Table 1: Percentage of matched arrivals & departures on train schedule per series number.

series number	matched departures (%)	matched arrivals (%)
500	81.9	81.9
600	85.9	85.9
800	62.4	62.4
1700	76.0	76.0
2000	86.6	85.6
2800	88.4	87.2
3000	54.0	54.0
3100	41.5	41.5
3500	71.9	71.9
4900	87.9	85.8
5500	5.4	5.6
5600	91.0	92.4
5700	89.1	91.5
6000	90.8	87.0
6100	84.0	83.2
6900	93.8	92.9
7400	49.8	49.8
7800	92.9	91.3
8800	88.7	87.0
11700	71.53	71.18

Stated in Section 2 not all departure and arrival times at Utrecht Central were available per trip. For these trips we traced back the last known location before the departure/arrival. In Figure 1 we can see for each last known location the distance to Utrecht Central. Approximately 99.9% of the observations are less than 5 km away from Utrecht Central. Therefore, we only estimate the remaining travel time for these observations, and remove the remaining 0.1% from our analysis.

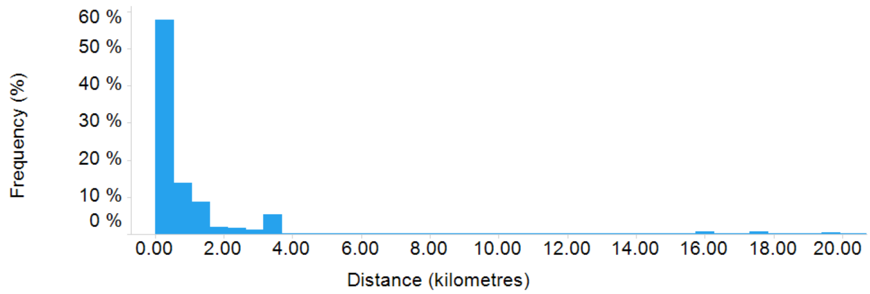

Fig. 1: Histogram of distance from last known location to Utrecht Central Station

3.2 Arrival and departure times estimation

In Figure 2 we see that the distribution of distances from Utrecht Central Station versus time upon arrival/departure has a high variance. Also given a series number and distance the time varies much. Therefore, for further calculations we will consider an optimistic, median and a pessimistic case, using the 10%, 50% and 90% quantile of the travel time per series number respectively.

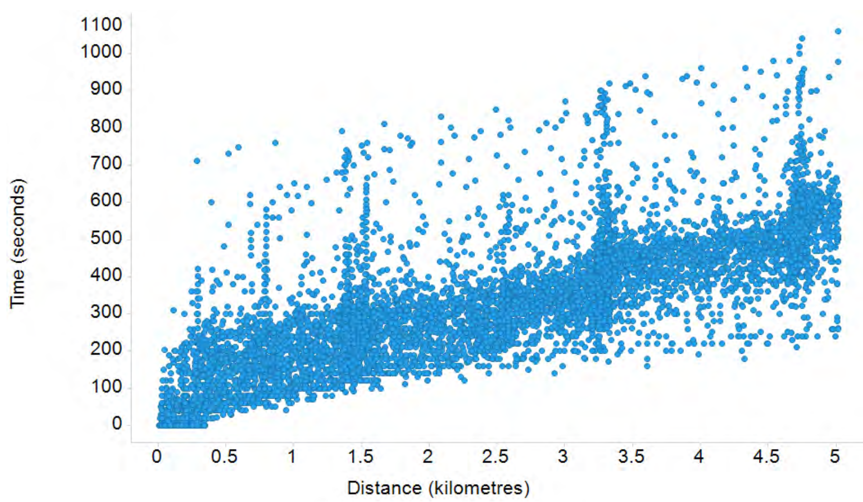

Fig. 2: Scatter plot of distance from Utrecht Central Station to location of observation against the time until departure/arrival

3.3 Train punctuality

In Table 2 we can see the percentage of delayed arrivals and departures. From this table we can conclude that in the median case a train arrives on time for 92.46%. This number is a bit lower than the 94%–95% the NS publishes in their annual report [4, p. 44]. This discrepancy could be due to the fact that in May 2017– Jun 2017 the NS performed worse than in 2016 and because the calculated percentage only takes into account arrivals at Utrecht Central Station. Also, notice that in the optimistic case the delayed arrival percentage will decrease compared to the median and pessimistic case. For departures, delays are more common in the optimistic scenario than in the pessimistic one. This makes sense as in an optimistic case the departure will be later to increase the transfer time. In Table 2 we observe that the departures are less frequently delayed than the arrivals. This could be due to the fact that the stop at Utrecht Central Station is shortened.

Table 2: Percentage of delayed trains and standard deviation of delays in minutes

scenario	departure		arrival	
	delayed (%)	std. deviation (minutes)	delayed (%)	std. deviation (minutes)
optimistic	3.08	1.76	6.50	2.51
median	2.54	1.73	7.54	2.65
pessimistic	2.15	1.99	10.15	2.88

Next to Table 2, in Figure 3 we can see the distribution of delayed arrivals and departures. This distribution seems skewed to the right.

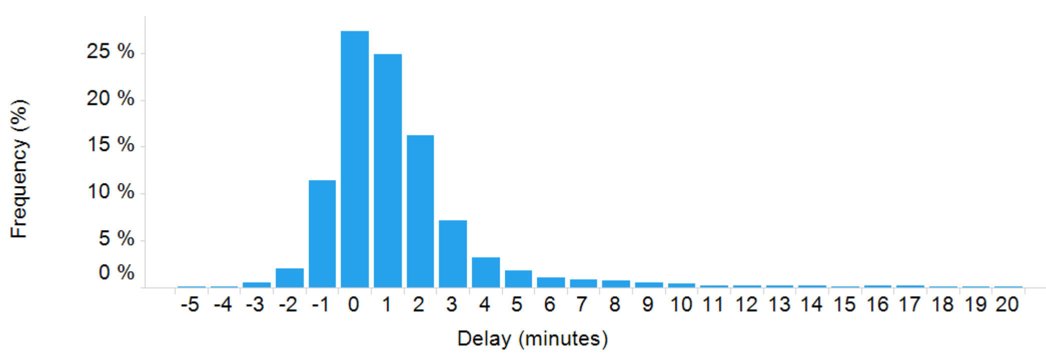

Fig. 3: Histogram of delay in minutes for arrivals (median scenario and x-axis maximum set to 20 minutes)

3.4 Transfer punctuality

In Table 3 the transfer delay statistics are given. We can see that the percentage of transfers delayed is much bigger than the arrivals delayed. We also notice that the variance of this transfer delay is considerable higher. Also, logically the average delay of a transfer rises per scenario.

Table 3: Percentage of transfers delayed (if transfer delay > 5 minutes), the average transfer delay and the standard deviation of the transfer delay per scenario.

scenario	delayed transfers (%)	avg. delay transfers (minutes)	std. deviation (minutes)
optimistic	11.26	0.83	5.96
median	16.14	1.73	5.94
pessimistic	21.42	2.12	6.53

The transfer delay is dependent on two things: the arrival and the departure. The effect of the arrival delay and departure delay on the transfer delay is shown in Table 4. This table shows that if an arrival is on time, the transfer delay behaves as we would expect. The worse the scenario, the higher the percentage of delayed transfers. For the delayed arrivals, we do not see this behavior in the numbers. If the departure is delayed, the percentage of delayed transfers is less than for more optimistic scenarios.

Table 4: Percentage of delayed transfers given the departure or arrival is delayed per scenario

% of delayed transfers

scenario	delayed arrival		arrival on time	
	delayed departure	departure on time	delayed departure	departure on time
optimistic	96.43	56.30	60.85	5.87
median	94.08	60.03	65.73	10.69
pessimistic	89.73	57.68	68.42	15.87

In Figure 4 we see the distribution of the delay of the transfer of the median scenario. The first thing to notice is the peak at 0 and the small peak at around 15 minutes and 30 minutes. The transfer delay can be negative sometimes. This can happen if the departing train leaves a tiny bit earlier sometimes. Also, this can happen if the the departing train has a delay, this makes it possible to still catch this train. Without a delay of the departing train, this would not have been possible. In Figure 5 we see the distribution of the delay of the transfers which are delayed. We see that the delay of a transfer is often 10 to 20 minutes. This is because a passenger is able to catch a train with a different series number than planned but with the same heading direction.The peak at 30 minutes corresponds to a passenger having to wait for the next train with the same series number.

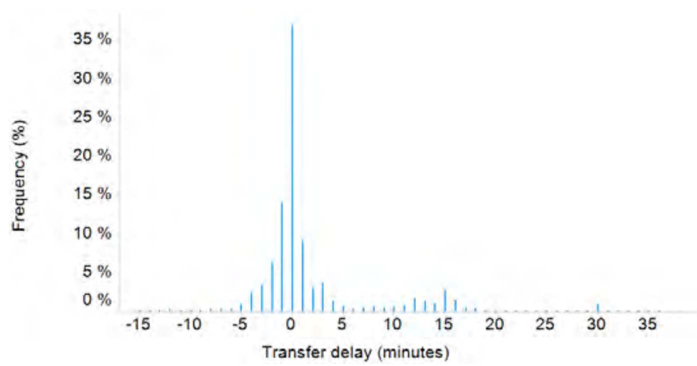

Fig. 4: Histogram of delay of the transfer in minutes (median scenario and maximum x-axis set to 40 minutes)

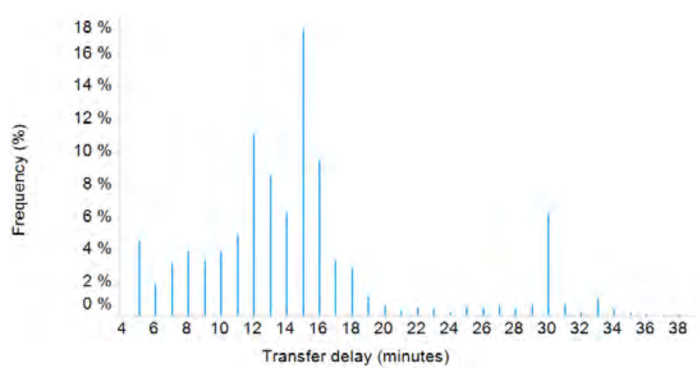

Fig. 5: Histogram of delay of the transfer in minutes of with a transfer delay of more than 5 minutes (median scenario and maximum x-axis set to 40 minutes)

In Table 5 we can see the percentages of the different departure train scenarios. We notice that the in approximately 40% of the cases, if an arrival is delayed, the passenger is still able to catch their planned train. Also, we see that the passenger is able to catch a a train with a different series number than planned for a great deal of the transfers. For a passenger, this flexibility is beneficial as a passenger does not always have to wait 30 or even 60 minutes for the next departing train.

Table 5: Percentage of transfers where the departing train is the same as planned, a different train (but same series) than planned and a different series number than planned. Data limited to transfers where the arrival is delayed.

scenario	same train as planned (%)	different train than planned (%)	different series than planned (%)
optimistic	42.2	7.6	50.1
median	42.1	8.8	49.1
pessimistic	39.4	8.7	51.9

Figure 7 in the appendix shows the arrival delay against the transfer delay. We see that the arrival delay and transfer delay are linearly dependent. Next to this, the variance does seem to rise with the arrival delay. This means for a passenger that the more the arrival is delayed, the more unstable the total travelling time will be.

4 Discussion

This research was designed to investigate the punctuality for passengers. This consisted of preparing the data and mapping the actual arrivals and departure to the train table. Next to this, the transfer efficiency has been investigated.

The first obstacle in this research was the missing observations in a trip for the departure or arrival at Utrecht Central Station. Due to the high percentage of trips missing these observations, skipping these trips was not an option. We estimated the missing travelling time for three scenarios: pessimistic, median and pessimistic, using the 10%, 50% and 90% quantile, respectively. These estimations do not fully guarantee that we captured the arrival or departure time correctly.

The planned and actual departing train at a transfer can be from different series in our computation. This is because we look at the heading direction of a passenger at a transfer. We do not constrain the passenger to take the train of the same series number as planned. This way we take into account the fact that many stations ca be reached with multiple series. We do constrain the passenger to take the same type of train for the planned and actual train. This will guarantee that a passenger won't take an intercity resulting in passing the passenger's end station. Also, this won't let a passenger take a sprinter when its planned departure train was an intercity. Unfortunately, there might be some cases that a passenger might not be able to reach the desired station using this technique. But constraining a passenger to take the train of the same series, does not seem to be a valid option.

The punctuality for passengers also bears in mind cancelled trains. In the data feed, these trains were not available. Therefore, we could not use this in our analysis. Also, from Table 1 we notice that the matching is not successful for each planned train. This missing portion can not be justified by cancelled trains as this portion of missing data is too high.

Currently, all the measured statistics are weighted per train and not per passenger. NS reports the passengers punctuality weighted per passenger, this gives a more complete statistic. Unfortunately, we did not have data available per passenger. Therefore, we could not replicate this punctuality for passengers weighted per passenger. In future research this would be highly recommended.

5 Conclusion

This paper shows that the distribution of the punctuality for passengers is a combination of multiple statistics. This punctuality for passengers captures the arrivals/departures delay, plus cancelled trains. We have obtained from the results that the train punctuality comes true to 92.46% and the arrival delay has a standard deviation of 2.65 minutes (median scenario).

We derived a new metric, the transfer punctuality, which shows the efficiency of a transfer. This transfer punctuality (83.86% for median scenario) is considerably lower than the train punctuality. This shows that the unreliability of arriving and departing trains have a significant impact on the transfer time. Even if the arriving and departing train are on time, the transfer punctuality is worse than the train punctuality. After the investigation of the correlation between the arrival delay and the transfer delay, we conclude that the these two measures are linearly dependent. However, the variance of the transfer delay increases with the arrival delay. This indicates that the total travelling time becomes more unstable if the arrival delay rises, next to the fact that the traveling time increases. Also, the distribution of the transfer delay in Figure 5 shows the fact that a transfer delay is highly correlated with the frequency of the train table. From this figure we can see that a passenger sometimes has to wait half an hour because its arriving train has a slight delay.

It is in the interest of the passenger how the delay of a transfer is distributed. One can imagine that a transfer delay that is normally distributed would be preferred over the shown distribution in Figure 4. If a passenger misses his train, the delay of the total travelling time will amount to approximately 10 minutes (median scenario). Quite often this transfer delay will be approximately 30 minutes. In 2010, an hour of time loss for a train passenger represent a value of 7.10 euros

[8, p. 15]. The transfer delay could also possibly result in a missed connection on a different mode of transport, i.e., getting your flight at Schiphol Airport.

This paper shows that the punctuality of passengers is not fully representing journey's success. The punctuality of passengers only shows the fraction of passengers which arrive at their final station with a delay less than 5 minutes. The distribution of the transfer delay is able to show the effect of connecting trains from other series than the planned departing train. Next to this, this transfer delay indicates the consequence of the frequency per series number.

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7 Appendix

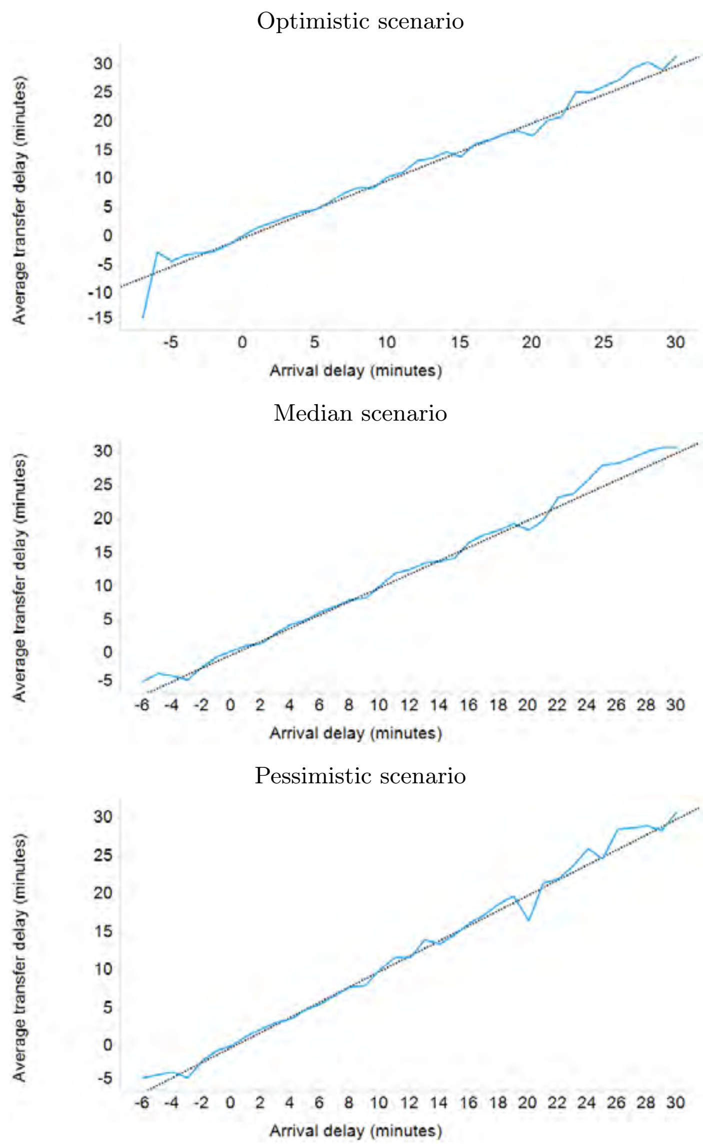

Fig. 7: Plot of arrival delay against the average transfer delay (blue) and the line $x = y$ (dotted grey)