

Advances in Measuring Pedestrians at Dutch Train Stations Using Bluetooth, WiFi and Infrared Technology

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Abstract As of 2014, three Dutch train stations have been equipped with automated pedestrian traffic sensors, as part of the SMART Station initiative of NS Stations. These stations are Utrecht Central station, Amsterdam Airport Schiphol train station and Leiden Central station. SMART Station consists of hybrid Bluetooth/WiFi sensors for tracking and infrared sensors for counting. Combining data from both sensor types results in useful insights into the pedestrian dynamics. In this paper, four SMART Station cases are presented. Firstly, an estimation of escalator capacity will be presented. Secondly, we will show the temporal and spatial flow characteristics of a very large bike parking facility. Thirdly, the use of train stations by non-train passengers will be explored. Fourthly and finally, the occupancy of a station hall will be explored.

1 Introduction

In recent history, train ridership in The Netherlands has increased significantly. A relatively limited number of large train stations has ‘absorbed’ a relatively large share of the total growth. The concentration of rail passenger traffic at specific train stations poses significant challenges on the pedestrian infrastructure of these stations. To get a better insight into the crowd challenges at its train stations, NS Stations—the stations and real estate division of Netherlands Railways (NS)—has initiated a program to measure pedestrian behaviour in a systematic and automated way.

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In 2013, we have presented our first paper on measurements of pedestrian flows at train stations using Bluetooth in The Netherlands [1]. The paper contains the main findings of our study into the route choice behaviour of passengers regarding vertical infrastructure at Utrecht Central station. Data of an experimental set-up of eight Bluetooth-only sensors at Utrecht Central station has been used.

In this paper, four cases are presented using data from permanent sensor set-ups with combined Bluetooth, WiFi and infrared sensors, which have been installed at three large train stations in The Netherlands. This paper is structured as follows. Section 2 describes SMART Station and—briefly—the logic behind it. Sections 3–6 cover the cases, with one case in each section. Section 7 concludes this paper.

2 SMART Station

The main objective of SMART Station is to measure pedestrian flows, route choice, activity choice, dwell times and occupancy of pedestrian infrastructure at Dutch train stations with an automated data collection system. The solution has to be competitive with traditional data collection methods on the more complex stations regarding costs and benefits. Moreover, data collection has to be performed in a way that the privacy of all station users is respected. Therefore, SMART Station has been following the guidelines for privacy-by-design [2]. Since the successful pilot in 2012, three of the largest train stations in the Netherlands have been equipped with sensors: Utrecht Central station, Amsterdam Airport Schiphol station and Leiden Central station, with respectively 250,000, 83,000 and 85,000 train passengers per average workday.

The basic concept of SMART Station is to combine multiple sensor and data processing technologies to measure pedestrian flows. Several experiments in 2011 and 2012 with various state-of-the-art technologies have shown that combining global and local measurements by different types of sensors delivers the best results regarding cost effectiveness and data quality [3]. This strategy enabled us to prevent compromises regarding measurement capabilities of individual technologies, but allowed to deploy the best of all available technology.

In the current configuration, Bluetooth/WiFi sensors from BLIP Systems are used for tracking, and infrared sensors from Irisys are used for counting. The Bluetooth/WiFi sensors track global movements and dwell times of mobile devices (i.e., smartphones, tablets and laptops). The infrared sensors count local passenger traffic at strategic points inside the station. Combining global and local data results in a detailed picture of pedestrian dynamics [3].

For many reasons, not all pedestrians are detected by the tracking sensors. To overcome this limitation, a penetration ratio is calculated by combining tracking and counting data. This ratio describes the ratio between the number of counts and the number of tracks at a specific site at the station. Similar to other studies, we have found a Bluetooth ratio of 5–10%. For the WiFi penetration rate, we have found a ratio of 20–25% [3].

3 Case 1: Upward Escalator Capacity at Utrecht Central Station

The first case consists of the estimation of the practical escalator capacity at Utrecht Central station. At this station, each platform is connected to the station hall by two pairs of escalators and one fixed stairway. Counting sensors have been installed at the escalators of platform 11/12. This platform is used by various train types—intercity and regional trains—and, therefore is found to have a representative passenger population for the whole station [4]. The sensors have been installed at the inflow and outflow section of the downward and upward escalator respectively (red line in photo in Fig. 1). This location is chosen to avoid incorrect measurements due to congestion in front of the escalator. Congestion or congested flow frequently occurs at the platform after the arrival of a train, and measurements at these sites should be avoided due to a known limitation of Irisys infrared sensors.

The counting sensor data is available from a 1-min aggregation level for both the upward and the downward direction. For the capacity estimation, a data set with measurements from 7.00 to 19.00 h from 1 January to 17 September 2014 has been created. Only the flow in upward direction from platform to station hall has been included as congestion only tends to occur in this direction. Arriving passengers (upward direction) are brought to the station in bulk due to train arrivals, while the arrival time of departing passengers (downward direction) is distributed over time between train departures. Filtering out incomplete measurements due to off-line sensors resulted in a data set with 74,700 min with counts in the upward direction.

All observations in the data set have been ordered to find the time frames in which the escalator was potentially used at capacity. In 1-min aggregated data, capacity traffic conditions have been found by selecting the pairs of subsequent minutes in

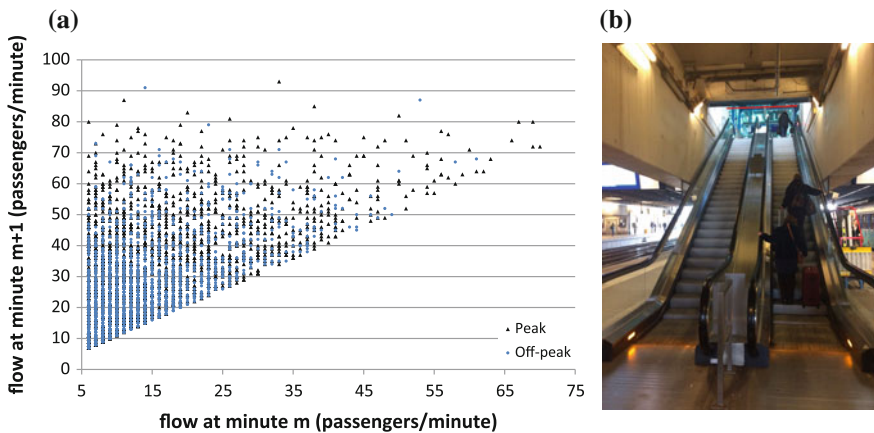


Fig. 1 From platform 11/12 to station hall (upward) escalator flows at Utrecht Central station: flows (a); situation (b)

which a number of pedestrians (>5) have been counted during the first (m) and second minute ($m + 1$). These pairs represent the traffic dynamic that an escalator gets congested shortly after the arrival of a crowded train. The queue at the platform starts to work as a buffer of pedestrians, which allows the flow at the escalator to reach capacity. The higher the counts during both minutes, the more likely it has been that the escalator has been used at capacity.

The data set consisted of 3,389 pairs of minutes (9.1 % of the total data set) which both— m and $m + 1$ —had counts larger than five. Figure 1 is a graphical representation of the data. In the graph, the pairs have been classified into off-peak and peak hours (7.00–9.00 h and 17.00–19.00 h). An estimation of the capacity of an escalator can be found by looking at the observations with the highest flow at minute $m + 1$ s. Based on the data, a capacity estimation of 75 persons per minute ($+/-5$) seems reasonable for peak hours, and 70 persons per minute ($+/-5$) for off-peak hours.

4 Case 2: The Use of a Large Bike Parking Facility at Utrecht Central Station

The second case covers the in- and outflow of a very large bike parking facility at Utrecht Central station, which has been in operation since July 2014. The facility is located right under the main station entrance at the non-city centre side (Jaarbeurs Square, at Jaarbeurs Convention Centre) and has a capacity for 4,200 bikes. For this analysis, a combined data set with tracking and counting data has been used.

For relating the flows to and from the bike parking facility to the train station, a tracking sensor has been installed at the entrance of the bike parking facility where people arrive and leave while wheeling their bikes. The pedestrian-only entry/exit on the other side of the bike parking facility is closely situated to the main entrance of the train station. This is one of the two main entrances which has been equipped with both a tracking and counting sensors. Therefore, the hourly penetration ratio of this entrance could be used to calculate the total flows from the tracking data.

The data set covered 15 days, from 2 to 16 September 2014. In this time frame, a total number of 165,927 complete routes has been generated based on the tracking data, which were related to this entrance of the station hall. During the same time frame, the counting sensors recorded a flow of 691,006 pedestrians, which is an average of slightly over 46,000 pedestrians per day. The busiest day was 9 September, with a total, bi-directional flow of 50,235. The average penetration ratio was 24 %, varying between 20 and 27 %, depending on the day of the week.

A total of 15,951 routes (9 %) has been identified to fit the condition of a detection at both the Jaarbeurs entrance of the station hall and the bike parking facility. Using the penetration ratio, the total flow is estimated at approximately 66,500, or a daily average of about 4,400. On the busiest day, the total flow reached over 5,700. As a typical passenger arrives with his bike at the station in the morning and leaves again

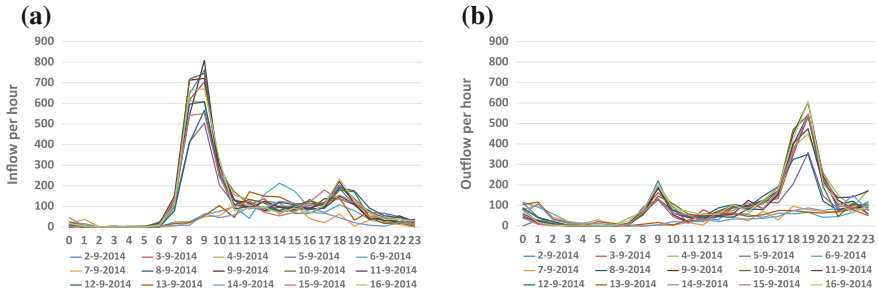


Fig. 2 Hourly inflow (a) and outflow (b) of the Jaarbeurs Square Bike Parking facility at Utrecht Central station

in the evening, this number is equivalent to approximately 2,850 bikes that have been parked in the facility during the day. So the occupancy ratio is estimated on 67 %, assuming that no one other than train passengers use this facility. Figure 2 shows the hourly inflows and outflows of the facility.

5 Case 3: Intra-city (Non-passenger) Flows in Utrecht Central Station and Leiden Central Station

Historically, many train stations have been built at the outer perimeter of cities. In the subsequent decades or even centuries after the establishment of the central train stations, many cities have grown towards the train station, as these provided main transportation links to other cities. Because the land on the city centre side of the train stations became scarce, cities started to grow at the other side of the station. Because railway tracks, particularly the railway yards, became a barrier between both city sides, many train stations also started to function as links between both city sides. This has resulted in intra-city, non-passenger, pedestrian flows of significant volumes. Because these pedestrians do not use trains, their movements are hardly captured in any data set that describes the primary function of the train station. The automated measurements at Utrecht Central station and Leiden Central station created the possibility to analyse these intra-city pedestrian flows over a longer time frame. For this case, two data sets have been used.

The first consists of combined tracking and counting data of Utrecht Central station, from 11 January until 24 April 2014. After removing the days with incomplete data, a total 84 days have been included in the data set, covering 753,859 complete routes (average of 8,975 per day). These routes represented pedestrian movements that fitted the condition that the pedestrian has been detected at both entrances at the train station with 30 min without being detected at any platform, but has been detected inside the station hall (non-passenger). From the counting data, the penetration rate has been derived. For this segment, the penetration rate varies between 17 and 25 %,

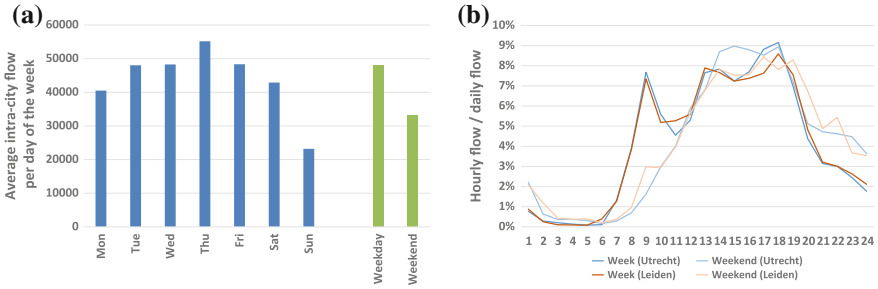


Fig. 3 Flows at the station. Total flows at Utrecht Central station per day and day type (a). Temporal distribution of intra-city flows at Utrecht Central station and Leiden Central station (b)

averaging at 21 %. The second data set consists of tracking data of Utrecht Central station and Leiden Central station of 1 to 29 April 2015. For Utrecht Central station and Leiden Central station, a total number of 219,223 and 39,604 routes has been included respectively, covering the intra-city flows during 24 h per day.

Figure 3 shows the results of the analysis. It shows that the station hall of Utrecht Central station is used by approximately 50,000 non-passengers on an average weekday. On weekend days, the intra-city flow is significantly lower, particularly on Sundays (20,000). Comparing the temporal distribution of the intra-city flows at Utrecht Central station and Leiden Central station, it becomes clear that the daily patterns are similar, both for week days and for weekend days. The evening peak of both week and weekend days occurs between 17.00 and 18.00 h and has a share of 9 % of the total daily flow.

6 Case 4: Occupancy at Utrecht Central Station

For estimation of the size of station halls, which usually combine the function of walking and waiting, both the number of pedestrians (flow) and the duration of their stay (dwell) are important factors. Therefore, station occupancy will be explored in this fourth and final case. The data is from tracking sensors in the station hall of Utrecht Central station.

Before the morning peak hour at Monday 2 March 2015, an overhead wire at one of the station tracks got damaged and caused total shut down of all train traffic to and from Utrecht during peak hour, due to the extremely inconvenient location of the incident [5]. This situation prevented departing passengers to leave the station by train. As most sources of train traffic information are situated in the central hall, many passengers decided to wait there. This caused an overload of the station hall.

The orange graph of Fig. 4 shows the occupancy of the station hall after the incident. The maximum occupancy was reached around 8.00 h, with approximately 3,000 mobile devices detected. This number was derived from determining the number of non-finished routes for each minute of the day. A non-finished route indicates that a

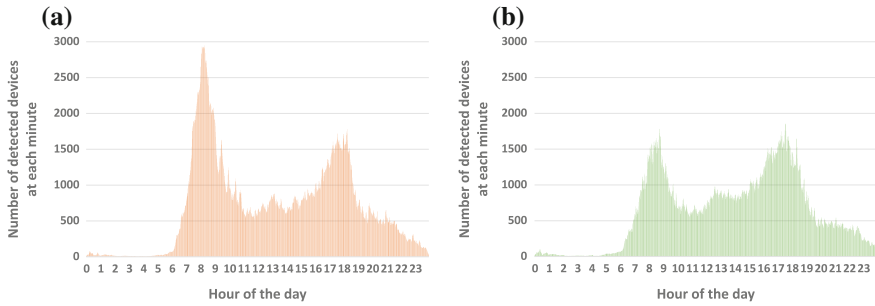


Fig. 4 Occupancy pattern at Utrecht Central station: major service disruption (Monday, 2 March 2015) (a); normal day (Tuesday, 3 March 2015) (b)

passenger did not finish his/her route (i.e. from entrance to platform) at that particular minute yet, but will do so at a later moment in time. Note that applying a penetration ratio of 20–25 % on this number of mobile devices results in an estimated occupancy of 12,000–15,000 passengers in the station hall. In contrast, the green graph of Fig. 4 shows the occupancy distribution during the next day (3 March 2015), when no service disruptions occurred. During that day, a peak of 1,800 mobile devices (7,000–9,200 pedestrians) is detected in the station hall.

A critical remark about this comparison has to be made. It is based on the assumption that pedestrians have not enabled or disabled Bluetooth or WiFi on their mobile device when they are in the station hall. The service disruption of 2 March could have triggered passengers who were waiting in the station to enable WiFi in their search for additional passengers. However, no counting sensors have been installed in this area, since they were located at the station entrance and at some escalators to the platforms. Therefore, we have no data to assess the validity of this assumption.

7 Conclusions and Future Developments

This paper has presented a broad selection of our recent insights from measurements of pedestrians at three large train stations in The Netherlands using Bluetooth, WiFi and infrared technology. These insights are extremely valuable for the design and operation of train stations.

The first case has shown that the escalator capacity is estimated to be 70–75 (+/–5) persons per minute for peak and off-peak hours respectively. The second case has shown the inflow and outflow of a very large bike parking facility with 4,200 places. The intra-city, non-passenger flows through train stations have been the central topic of the third example. It has shown that these flows through train stations consist of tens of thousands movements per day. The fourth case consisted of an example of station occupancy, which is the product of flow and dwell times. It has been shown that a major service disruption can cause a two thirds increase in the peak load of the pedestrian space of a train station.

Currently, NS Stations is working on the expansion of SMART Station at Amsterdam Airport Schiphol by installing counting sensors at stairs and escalators. These sensors will generate the data which is required to calculate the penetration ratio. This will proof to which extent Schiphol train station is different from other large train stations in city centres, due to the location at the airport. Moreover, SMART Station sensors are being installed at Amsterdam Central station in January 2016. This station is mainly used for very large intra-city flows. Therefore, measurements at this station will reveal whether the observed pattern of Utrecht Central station and Leiden Central station can be considered as generalised. And finally, a current discussion with stakeholders might result in a SMART Station at Amsterdam South station, which is located at the Central Business District of Amsterdam. This station is amongst the fastest growing stations in the country and is expected to be faced with pedestrian congestion within a couple of years.

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