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An Application of New Pedestrian Tracking Sensors for Evaluating Platform Safety Risks at Swiss and Dutch Train Stations

Jeroen van den Heuvel, Jasmin Thurau, Martin Mendelin, Rik Schakenbos, Marcel van Ofwegen, and Serge P. Hoogendoorn

Abstract Due to rapid rail passenger growth in the last years, crowding challenges have risen at several stations in Switzerland and The Netherlands. Particularly at platforms, safety risks can increase when a station is operated near or at pedestrian capacity. Therefore, Swiss and Dutch station managers started several initiatives to measure crowding-related safety risks. Recently, pedestrian measurement technology has improved substantially. New technology is capable of anonymously tracking individual pedestrians within a predefined area under high intensity conditions. This technology has not been implemented at train stations before. Therefore the Swiss and Dutch station managers have developed and applied a methodology to determine the validity of the data which are generated by the newest generation of pedestrian measurement systems at the stations of Bern (CH), Amsterdam Zuid, and Utrecht Centraal (NL). This paper presents the results of the tests in both countries and their (first) implications for science and practice.

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1 Introduction

Due to rapid rail passenger growth in the last years, crowding challenges have risen at several stations in Switzerland and The Netherlands. Particularly at platforms, safety risks can increase when a station is operated near or at pedestrian capacity.

The safety line is the line at the platform between the circulation/waiting zone and the platform edge near the tracks [5]. Passengers are observed to cross this safety line at busy platforms more often than at less busy or more spacious platforms. Platform enlargement projects take years to implement and are extremely costly. In most cases risks cannot be reduced sufficiently by a rearrangement of platform objects. Risk-targeted, operational interventions are limited by a lack of insight into passenger behavior at platforms, which in turn are limited by a lack of empirical data.

Until recently, pedestrian measuring systems at Swiss and Dutch train stations have been used only for counting the number of pedestrians at a predefined area (occupancy) or passing a counting line (flow rate). Advanced systems have not been sufficiently accurate as well due to challenging semi-outdoor environment with high flow rates at a train station (see Fig. 1).

During the last years, pedestrian counting technology has improved substantially. New technology of the Swiss company ASE—hardware and software—is capable of anonymously tracking individual pedestrians within a predefined area under high intensity conditions. This has created the potential of measuring pedestrians' paths through an area (trajectories) and to assess walking speeds and densities under different traffic conditions. As this technology has not been applied at train stations before, Swiss and Dutch station managers have tested the newest generation of pedestrian measurement systems in practice to assess the quality of the data.

Fig. 1 Crowding at train station platforms. Left: Bern SBB, track 3/4, 8 March 2016, 7.03 h; Right: Utrecht Centraal, track 5, 7 December 2015, 8.01 h. These pictures are representative for peak hours at regular work days

This paper is structured as follows: in the next Sect. 2, sensor data quality is defined. Validity definitions are based on a review of literature and an assessment methodology is proposed. Section 3 covers the experiments, and Sect. 4 the results. This paper is concluded in the fifth and final section with conclusions and recommendations for science and practice.

2 Path Data Quality Definition

The sensor data describes the paths of pedestrians who have used the measurement area for walking or waiting, in existing research also referred to as "trajectories." The data for each path consists of an anonymous ID and its spatial coordinates (x and y) at each moment in time (t). The sensors register these data ten times per second for each path ID. With this level of detail, the data resolution is extremely high. High resolution, however, is not an indicator of data quality, which in this context is defined as validity: the extent to which the paths in the data accurately describe the real location of the corresponding pedestrian at each recorded timestamp.

To assess the quality of the path data from the sensors, a definition has been developed based on the previous research. The PhD research by Daamen [3] has been one of the first publications with a detailed description of a validation procedure of microscopic pedestrian model output. In their validation of automatically extracted pedestrian trajectory data from video recordings, Boltes et al. [1] have identified occlusion caused by height differences between pedestrians as a source of measurement error. Occlusion occurs when a relatively small person is standing in the "shadow" of a taller person in areas relatively far away from the sensor. These errors are caused by the situation in which the sensors are deployed, not by the sensors themselves. In their state-of-the-art overview on measurement techniques for slow mode travel behavior, Daamen et al. [4] describe detection, location, and identification as the fundamental characteristics of Bluetooth and WiFi measurements of travel behavior. Detection is about capturing correctly if a pedestrian is present in the measurement area. Location is about the correct representation of the position of each pedestrian in the measurement area. Identification refers to attributing the correct identification to each measurement of each unique pedestrian.

Based on the existing research, the data quality levels have been defined for this study, in order of increasing complexity:

1. **Correct count**: the degree to which the number of pedestrians in the data who have passed a line during timeframe Δt (flow) or who have been present in a specific area (density) at time t is according to reality;
2. **Correct position**: the degree to which the x- and y-coordinates of all pedestrians in the measurement area during a timeframe t is according to reality;

3. **Stable identification**: the degree to which the x- and y-coordinates of a unique pedestrian have been linked to the same ID in the sensor data during the total time the person has been in the measurement area;
4. **Path continuity**: the degree to which a sequence of x- and y-coordinates with the same ID during total time describes the real path of a unique pedestrian.

For this study, we have used level 4 (path continuity) as data quality indicator. Firstly, because from a research perspective, this study imposed no limits on which technical capabilities of the sensors could be tested. Secondly, because from a practical perspective, individual behavior in some cases is an important factor in assessing safety risks.

3 Experiment Setup

The unavailability of any ground-truth data with a similar level of aggregation as the sensor data has been a validation challenge to overcome by the research methodology. Another challenge has been the combination of an extremely dynamic character of pedestrian behavior at train platforms, combined with large numbers of pedestrians present at the same time (particularly at peak hours). This combination makes it extremely time consuming to make a structured comparison of the data from the sensors and empirical observations of the same situation from another source (i.e., CCTV-footage or outdoor observations) in an uncontrolled environment. Performing experiments in a controlled environment (similar to [3] and [1]) would have been inconsistent with the research objective, as the objective has been linked to the practical use of the sensors in real-life train station environments. Moreover, a significant number of sensors already had been installed at the stations of Bern (CH), Amsterdam Zuid (NL), and Utrecht Centraal (NL). This offered the unique opportunity to perform experiments without the need to purchase and install sensors for research purpose only. So for this study, we have chosen for controlled experiments at the three stations where the sensors already had been installed.

The experiments have been performed in the context of our research on the use of the danger zone at train platforms (see [5]). The validation of the correct position of pedestrians at the platform before train arrival(s) in the sensor data has been the main objective of this experiment. As indicated in Fig. 2, a pedestrian is in the danger zone when standing or walking with at least one foot at the track side of the safety line at the platform. Both feet at the safety line or at the non-track side of the safety line are considered as safe. The objective is to assess if measurements are according to reality, with a small margin of measurement error. For this experiment, we have chosen to set the margin of error at ± 10 cm or approximately a foot width. In practice, there is no need for a higher accuracy.

For the implementation of the experiments, a group railway and research staff has been recruited; as test person or for assistance in performing the experiment; all have been wearing safety vests and have been instructed on safety risks and procedures.

Fig. 2 Safety line at platform of Bern (CH); red arrow is "in danger zone"—indicator

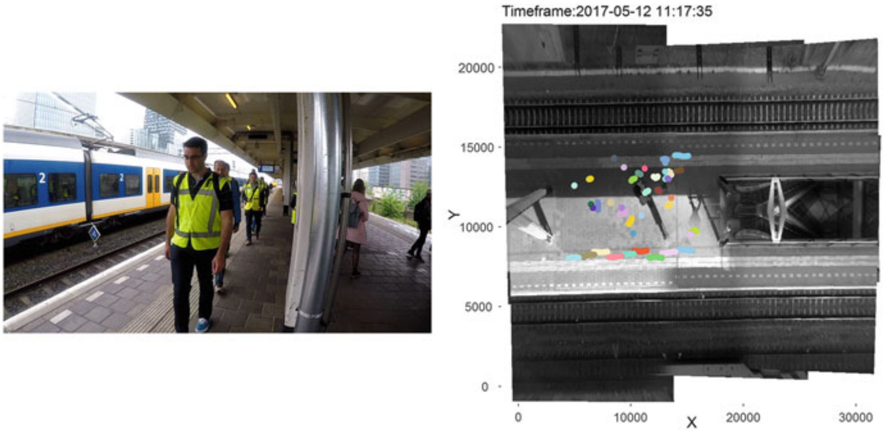

Fig. 3 Left: impression of experiment "at of beyond the line" at track 3 of Amsterdam Zuid (NL); Right: graphical representation of data collected during the same experiment

To minimize safety risks for the railway staff and inconvenience of train passengers, each run was performed directly after departure of a train during off-peak hours only. In Switzerland the experiments have also been used to identify the safety line in the data. There, the experiments were conducted at the boarder between safety and danger zone. To get sufficient data for validation, four runs per track have been performed with three positions simultaneously, each representing a degree between safe and unsafe: 1. next to the line, 2. with one foot at the line, and 3. with both feet at the line. For Amsterdam Zuid, the experiments have been performed for two tracks (3 and 4). This resulted in 2 tracks $\times$ 4 runs $\times$ 3 positions $\times$ 3 test persons per position = 72 experiments. The left part of Fig. 3 gives a visual impression of the experiments performed at Amsterdam Zuid. Similar runs have been performed at Utrecht Centraal (NL; 36 experiments) and Bern SBB (CH).

During the experiments, the sensors have measured the location of each pedestrian in the measurement area with an interval of 10 times per second. The right part of Fig. 3 gives a graphical representation of this data at track 3/4 of Amsterdam Zuid for the indicated timeframe. Note that this figure shows data of 10 observations during 1 s. The small dots represent passengers who were standing, while the larger shapes represent pedestrians who were walking. From the figure, the formation of 9 test persons at three positions can be recognized.

For evaluation, the non-parametric k-nearest-neighbor-based regression method LOESS has been used [2]. With LOESS, the Y-positions (along the platform width) for a smoothly fitted line for each run have been determined for all X-positions (along platform length) of each ID in their order of occurrence in timeframe Δt. Sensor data quality has been assessed by a relative comparison of the Y-position of all data points for each individual test person (see Fig. 3) against the LOESS-line, which has been derived from all data points per position in the formation of test persons in the same run.

4 Results

Figure 4 shows the regression analysis on the data of a well-assessed run at track 3 of Amsterdam Zuid (NL). The three test persons have walked at the second position (with one foot at the safety line) in the formation of nine test persons. The line in the graph indicates the LOESS-line of the measurements of the three test persons. The gray area refers to the allowed measurement error ($\pm$10 cm). The up/downward movement in individual measurements clearly shows the swaying which is typical for pedestrian movement. The red dots outside the gray area show that one test person (Hans) deviated from his path during a short segment of his path. This observation in the data has been confirmed by the video recordings made during the experiments. All 36 experiments at track 3 of Amsterdam Zuid have resulted in similar outcomes. Moreover, during the experiments at Bern SBB (CH), the divergent behavior of test persons and support staff could be easily distinguished in the datasets.

Figure 5 shows the results of a badly assessed run at track 4 at the same platform, for the same position, and the same test persons. In this graph, it is clearly visible that the ID of the second test person (Marcel) is lost after approximately 13 m. Further inspection of the data revealed that the path ID got lost. The path continued with a new ID, which has been caused by an unsuccessful transfer of the ID between two sensors. All 36 experiments at track 4 of Amsterdam Zuid have resulted in similar outcomes.

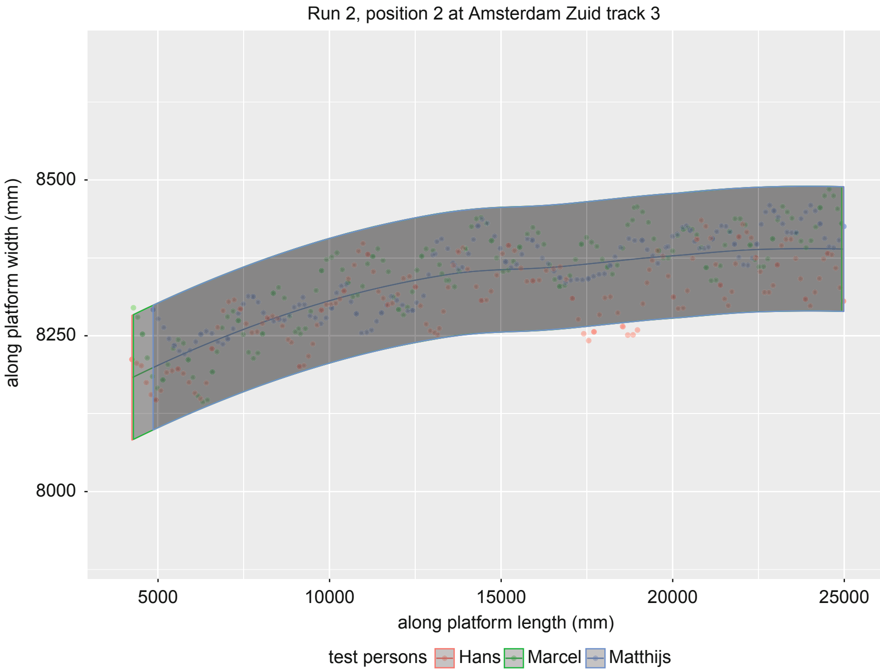

Fig. 4 LOESS analysis of run 2 and position 2 at track 3 of Amsterdam Zuid (NL)

Most probable cause is a slightly different position of one sensor at the track 4 side of the platform, compared with the same set of sensors at the track 3 side, where this issue did not occur. The 36 experiments at Utrecht Central station (track 5) have revealed that the issue of discontinued ID's also can occur due to objects which are located between the sensors and the measurement area at the platform. For example, train information screens, lighting, signing, and columns can cause "object shadows" in the measurement area.

In addition to the sensor technology, ASE has developed a post-process path stitching algorithm at its data server. This algorithm can be used to reassign the correct ID to paths for which the ID has been replaced by a new ID, while in reality both path sections are generated by the same pedestrian. Figure 6 shows the results of the same experiment. The only difference is the application of the path stitching algorithm on the data. The continuation of the path of test person 2 (Marcel) shows that the stitching has been successful.

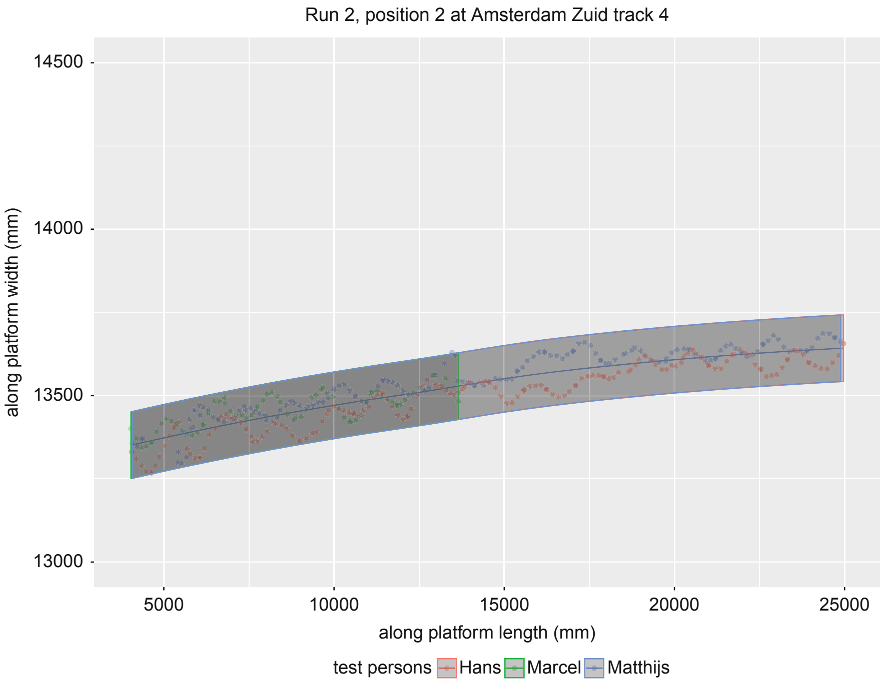

Fig. 5 LOESS analysis of run 2 and position 2 at track 4 of Amsterdam Zuid (NL)

5 Conclusions

The experiments at stations of Bern (CH), Amsterdam Zuid (NL), and Utrecht Centraal (NL) have shown that the pedestrian measurement technology of ASE is capable of delivering a high degree of accuracy of pedestrian measurements at train stations, even at the highest level of complexity (path continuity) that has been defined for this study. These data open up the possibility to research patterns in individual and collective passenger behavior and safety risks at platforms. This conclusion is supported by an extensive data analysis, combined with visual comparisons between data of individual paths and video recordings made during the experiments. The natural swaying of pedestrians, inconsistencies in test person behavior and even the divergent behavior of pilot stewarts and test persons can be detected in the data and linked to visual observations during the experiment.

The experiments have also revealed the importance of a well-designed and installed sensor installation. The experiments at track 4 of Amsterdam Zuid (NL) have revealed that a minor misalignment in the sensor positions can cause significant issues with handing over path IDs between sensors. The experiments at track 5 of Utrecht Centraal (NL) and Bern SBB (CH) have revealed a similar issue due to object shadows on the platform. These challenges can be overcome by increasing

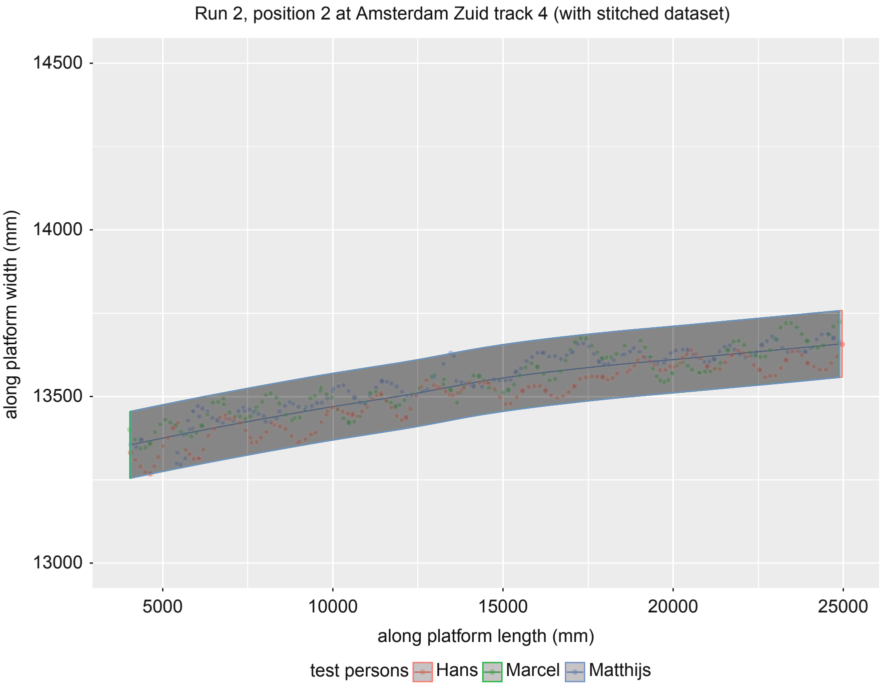

Fig. 6 LOESS analysis on stitched dataset of Fig. 5

the number of sensors, at the price of increased investments and operating costs. Before this is considered, there should be a clear need for data with an accuracy at the highest level of complexity. If the data user is only interested in correct counts and/or positioning of pedestrians in a measurement area without the need of stable IDs, a lower number of sensors can be sufficient.

Alternatively, post-measurement stitching of paths can be considered. Our study has shown that this can solve ID-inconsistencies in the data. However, the conditions for successful or unsuccessful stitching are a topic for further research. The same applies to the evaluation of data quality when high densities occur (i.e., peak hours) and/or when passengers travel with large objects (i.e., luggage or bikes). During the experiments of this study, several tests have been performed with measurements at high densities. The data of these experiments has to be analyzed to assess data quality under more challenging pedestrian traffic conditions.

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