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Research Article

Pedestrian Patterns at Railway Platforms during Boarding: Evidence from a Case Study in Switzerland

Giulia Dell'Asin [1] and Johannes Hool [2]

[1] *SBB CFF FFS Infrastructure, Asset Management and Technology, Bern 3000, Switzerland*
[2] *Schweizer Radio und Fernsehen (SRF), Market & Audience Research, Zürich 8052, Switzerland*

Correspondence should be addressed to Giulia Dell'Asin; giulia.dellasin@sbb.ch

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The boarding/alighting process at railway platforms is an important determinant of the railway system performance and depends on the characteristics of passengers, the layout of the platform, and the rolling stock. This research aims to increase the understanding of the process, providing a methodological approach to model the passengers' behaviour when boarding at railway platforms. Adequate criteria were selected to define the so called "boarding cluster" and an easy mechanism was developed to select the boarding clusters. Passenger flow data collected at Bern railway station in Switzerland was used to test the proposed approach. The results show that (a) the clusters near the doors grow in the longitudinal direction with a rate of 6:1 between the length and width of clusters, and that (b) the growth curves rise quickly when clusters are still small, i.e., at the beginning of the boarding/alighting activity. Further research is needed to extend the validation of the model, considering other variables, such as critical pedestrian densities which occur at specific hot spots near obstacles at platforms.

1. Introduction

The platform train interface (PTI) is a crucial component of railway stations because of the high interaction between the three main players of the system, i.e., passengers (human behaviour), platforms, and rolling stock (design aspects). The measurement and understanding of the PTI and the pedestrian dynamics during the boarding/alighting process at railway platforms, which begins a number of seconds before the train arrives at the station, could lead to more effective decision making in operational activities and crowd management [1, 2].

The boarding/alighting process is an important determinant of the railway system performance and passenger service quality at railway stations for two reasons. Firstly, the length of the alighting and boarding activities directly determines the length of the dwell time, that is, the time a train stands at the platform allowing passengers to board and/or alight, and has a significant effect on timetable robustness and network efficiency [3, 4]. Secondly, the process itself encompasses several variables relating to human and design factors, thus also influencing safety, comfort, and functional issues at railway platforms.

Boarding/alighting activities are dependent on the characteristics of passengers, such as the number of alighting and boarding passengers, their spatial distributions over platforms, the luggage load and the passengers' discipline [5–7]. Furthermore, the layout of the platform impacts boarding/alighting due to the platform's available area, the design and location of the platform's accesses and furniture, the horizontal and vertical train-platform gap and the existence of platform "keep clear" zones [8–10]. Finally, rolling stock affects boarding/alighting because of the number and width of the doors, the seat capacity, and the interior layout of the vehicles [11–14].

Previous research on boarding/alighting activity focused mainly on the length of alighting and boarding time and its impact on dwell time. As expected, it showed that boarding/alighting times (and dwell times) tend to increase when the distribution of passengers over the platform is unequal

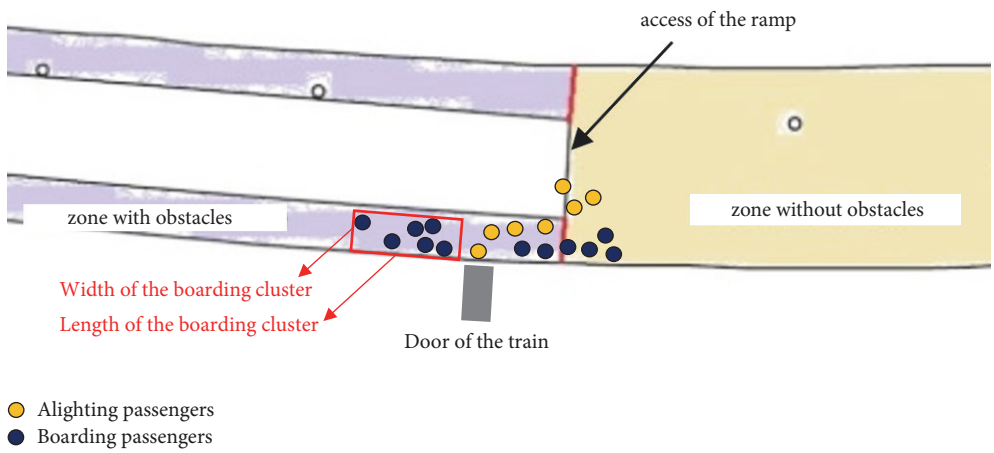

Figure 1: Boarding clusters along obstacles (narrow zones) on railway platforms. In [15] the clusters are represented by a rectangular shape (width and length) which is aligned in the longitudinal direction of the platform.

[4], the vertical gap between platform and vehicle floor is big [16], and the door width is narrow [17].

However, relatively little work has been carried out to understand boarding activity at railway platforms. The general objective of this research is to increase the understanding of the process, providing a methodological approach to analyse boarding passengers' behaviour and their interaction with the spatial layout before getting on the train. This study focuses on a microlevel analysis, which means that pedestrian patterns are analysed in correspondence of train doors and that no statements can be made about the distribution of boarding passengers along the platform. Alighting patterns are not explored in this study. The model is tested using data collected at Bern railway station in Switzerland.

As a specific objective, this research aims to validate the approach suggested to model passengers' behaviour when boarding at Swiss platforms in the presence of narrow zones [15]. This empirical approach is based on observations of pedestrian behaviour which were collected at different railway platforms in Switzerland during the last five years. As shown in Table 1 the Swiss Federal Railways have identified fixed values to define the width of the boarding clusters, that is, the width of the platform required by passengers while waiting for boarding, as calculated from the platform's edge (see also Figure 1). The values are set matching the number of boarding passengers per door, and the distance between the platform's edge and the obstacle on the platform. A minimum of 0.6 meters was defined, since this is the reference value of the average body ellipse of an adult [18]. The simplified approach assumes that the maximum density in the cluster of boarding passengers is about 3 persons per square meter and that the queue grows faster in both the longitudinal and the transversal direction of platforms with a rate of 3:1.

The article is structured as follows. Section 1 provides an overview on the topic of boarding/alighting and introduces the objective of the study. Section 2 focuses on the data and methodology. Section 3 presents the results of the application in the case study of Bern railway stations. Section 4 provides conclusions and highlights the further work required in this research field.

2. Materials and Methods

2.1. Methodological Approach. The methodology to analyse passenger behaviour prior to boarding a train was developed in this research, taking into account the characteristics of tracking sensor data which were available in the case study of Bern (Section 2.2) and can be described in three steps.

The first step focuses on data preprocessing. Firstly, non-plausible data needs to be removed from the data set because of bias due to blind spots caused by the presence of small obstacles, such as pillars or erroneous ID assignation in the case of high passenger density on the platform. Secondly, data is aggregated, which means that the required data is extracted from the data set on a one second interval basis. Therefore, single passenger movements can be detected second per second and other metrics, such as walking speed, can be easily calculated to describe passenger behaviour during boarding.

The second step focuses on selecting the adequate criteria to define the so called "boarding cluster", i.e., the aggregation of (boarding) passengers near the train doors when they are about to board (see also Figure 1). Two important factors were considered in the definition, building on the research of Löhner [19]. Firstly, all passengers in the cluster are assumed to have the same behaviour. Qualitative field observations of queuing behaviour at Swiss railway platforms show that boarding passengers tend to cluster beside the doors rather than in front of them, giving way to alighting passengers and thus leading to an organised boarding/alighting process. Boarding and alighting can therefore be treated separately for each door. This statement supports the decision to

Table 1: Definition of the width of the boarding clusters, which is calculated matching the number of boarding passengers per door, and the distance between the platform's edge and the first obstacle on the platform [15].

		Distance between the platform's edge and the first obstacle on the platform [m]					
		1.4	1.5	1.6	1.7	1.8	2.0 (*)
Number of boarding passengers per door [P/door]	2	0.60	0.60	0.60	0.60	0.60	0.60
	4	0.60	0.70	0.80	0.70	0.70	0.75
	6	0.60	0.70	0.80	0.80	0.80	0.85
	8		0.70	0.80	0.85	0.85	0.90
	10			0.80	0.90	0.90	0.95
	12				0.90	0.95	1.00
	14				0.90	1.00	1.05
	16					1.00	1.10
	18						1.10
	20						1.10
	> 20						1.10

(*) In case of distances which are greater than 2.0 meters no values were defined. Further analysis is needed to define the width of the boarding clusters.

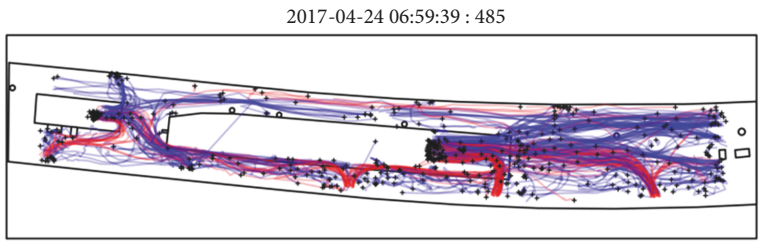

Figure 2: Plot of all passengers' paths to identify the position of train doors (blue = boarding passengers; red = alighting passengers) in the case study of Bern.

focus on the boarding process in the proposed approach (alighting passengers are not part of the cluster). Secondly, the formation of clusters depends on different variables, such as the density and walking speed in the cluster, as well as the duration of the cluster itself.

In this research the boarding clusters are defined through the following criteria:

(0) Only the boarding passengers on the platform belong to the cluster. Alighting passengers, who get off through the train door which is relevant to the cluster, are not considered.

(1) The average walking speed of the passengers in the cluster is less than 0.4 m/s for at least 3 seconds. Assuming Δs_i represents the distance covered by each pedestrian i during the same fixed temporal interval $\Delta t_i = 3$ *seconds* and that N is the number of boarding passengers in the cluster C,

$$\frac{\sum_{i=1}^{N} (\Delta s_i / \Delta t_i)}{N} < 0.4\ m/s. \tag{1}$$

(2) A cluster is made of a network of passengers. A passenger is assumed to be part of a cluster if the interpersonal space between himself or herself and at least one passenger in the same cluster is less than 120 cm. With this threshold is supposed a level of service lower of B in queuing and waiting areas [20]. Assuming s_i and s_j represent the spatial positions of two pedestrians, i and j, and the pedestrian j belongs to the boarding cluster C,

$$if\ s_i - s_j < 120\ cm\ then\ i \in C. \tag{2}$$

(3) A cluster exists only when the network (criterion 2) exists for at least 3 seconds. With reference to criterion 2,

$$\begin{aligned} &if\ s_i - s_j < 120\ cm, \\ &\forall i\ for\ at\ least\ 3\ seconds\ then\ C\ is\ a\ boarding\ cluster. \end{aligned} \tag{3}$$

(4) The distance between the train door and the first passenger in the cluster is at least 2 meters. Assuming s_i and s_D represent, respectively, the spatial positions of the first pedestrian i and of the reference door D,

$$s_i - s_D < 2\ m. \tag{4}$$

(5) In the cluster there are at least 3 passengers. Assuming N is the number of boarding passengers in the cluster C,

$$if\ N > 3\ then\ C\ is\ a\ boarding\ cluster. \tag{5}$$

The third step focuses on developing an easy mechanism to select the boarding cluster in order to answer the research questions:

(a) The position of train doors along the platform is identified thanks to the analysis of passenger flows on the platform. Since the identification can not be automatised, it is necessary to carry out a manual analysis, plotting all passengers' paths during the 30 seconds before and after the arrival of the train, per train and per day (Figure 2).

(b) The boarding cluster per train door is then identified by analysing passengers' movements near each train door, in a defined rectangular grid measuring 14 m in length (7 m from the train door, per each side) and 4 m in width during a defined temporal range of 135 seconds (15 seconds before the train arrival and 120 seconds after). In accordance with the goals of the investigation, the two worst boarding clusters per door (one per side) are finally selected, that is the two clusters with the *largest shape*. In the exploratory phase, the authors also tested the identification of clusters according to the highest density, but results were not consistent.

As regards the shapes of the cluster different models were tested (Figure 3): the minimal bounding box (MBB), the minimal bounding ellipse (MBE), and the minimal bounding horizontal box (MBHB). The MBB and the MBE group the observations in the minimal rectangle and the minimal ellipse, respectively. According to these two approaches there are no constraints as to the orientation of the shapes. The MBHB considers the maximal dimensions in the longitudinal and transversal direction of the platform. In this case the sides of the box are always either vertical or horizontal, parallel to the coordinate axes which are given as reference (the longitudinal and transversal direction of the platform). The three models statistically differ from each other and from the convex hull, i.e., the smallest convex polygon containing the points (Figure 4).

In this research, the shape was defined by modelling the data with a MBHB shape for two reasons: (a) it is a conservative solution, as it occupies the biggest area and (b) it helps in the interpretation of data, as the boarding clusters (queues) are generally aligned in the longitudinal direction

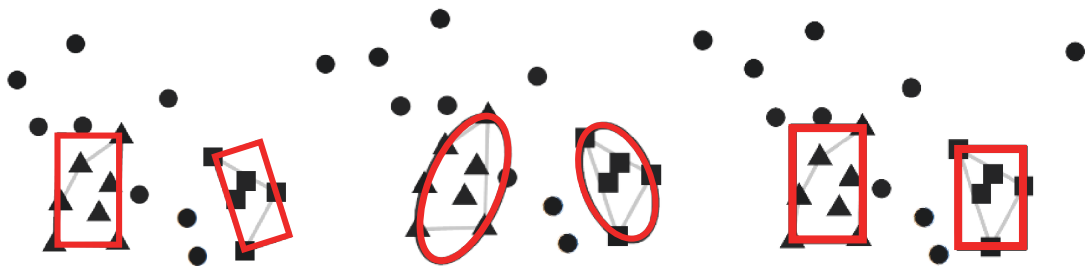

Figure 3: Modelling the boarding clusters: (a) minimal bounding box (MBB); (b) minimal bounding ellipse (MBE); (c) minimal bounding horizontal box (MBHB). The grey shape represents the convex hull, i.e., the smallest convex polygon containing the points. The red shape represents the selected model ((a) MBB; (b) MBE; (c) MBHB). Alighting passengers are represented by bullet points; boarding passengers by triangles (left side of the door) and squares (right side of door).

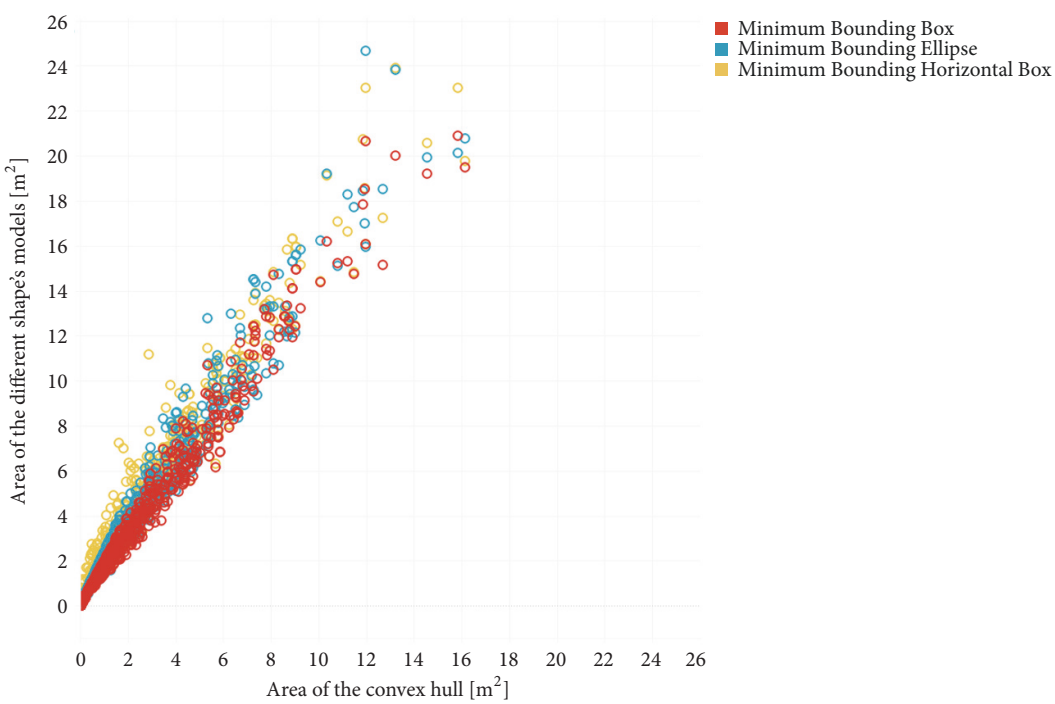

Figure 4: Plotting the different models versus the convex hull.

of the platform, as the Swiss approach also assumes [15]. Assuming the edge of the platform represents the x-axis of a Cartesian system, the four sides of the MBHB shape can be determined through the position of four pedestrians (points) in the clusters:

(i) The y-coordinate of the highest point defines the top of the rectangle

(ii) The y-coordinate of the lowest point defines the bottom of the rectangle

(iii) The x-coordinate of the leftmost point defines the left side of the rectangle

(iv) The x-coordinate of the rightmost point defines the right side of the rectangle

No assumptions are made on the volume of pedestrians, which were considered as punctual observations (the sensors register the pedestrian position over time considering their heads as reference), but the MBHB shapes were modified adding 30 cm per each side of the rectangle, thus considering the volume of the passengers at the border of the clusters, since the reference value of the average body ellipse of an adult is about 60 cm wide [18].

The selection of the cluster is carried out through a density-based clustering algorithm DBSCAN which is designed to discover clusters of arbitrary shape [21]. Data is firstly filtered according to criteria 0 and 1 and then selected, per each door's side, accordingly to the Shared Nearest Neighbour Clustering which consider requirement 2 and 5. Clusters are then filtered according to requirement 3 and 4. Finally the two clusters with the largest shape, one per each

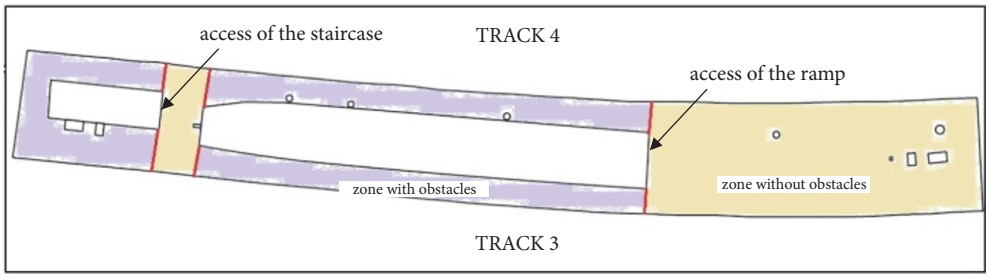

Figure 5: Layout of the study area: platform 3/4 in Bern railway station. The safety line is not represented in the figure.

side, are identified. In current work, all codes were written in R software.

2.2. The Case Study of Bern. Passenger flow data collected at Bern railway station was used to investigate pedestrian patterns when waiting to board the trains. Bern railway station is one of the most crowded stations of the Swiss railway network. In 2017, on average 324,000 customers used the station per workday, including passengers, retail customers, and transit flows [22]. Because of high passenger demand, railway platforms in Bern have reached the limits of their capacity during peak hours. The occurrence of congested situations before, during and after the arrival of the trains has recently grown, according to the admissible values of the Swiss technical guideline to design stations [15]. Today crowd management measures are locally implemented to avoid dangerous situations and significant investments are planned in the long term, since passenger volume is expected to grow by 40% by the year 2030 [23]. In this scenario, the growth of passenger demand would lead to congestion even during off-peak hours and, consequently, to dangerous situations for passengers on platforms as well as negative effects on operational issues, such as dwell and transfer time.

The current study was performed by processing tracking data acquired through stereo sensors which have been installed at platform 3/4 since December 2016. The sensor system is provided by ASE AG (Zürich, Switzerland) and consists of a grid of 20 units (sensors), covering the central area of the platform with a trap length of 60 meters. The sensors detect pedestrian flows with high precision [24] recording passenger movements in decimal fractions of a second. In the analysis, twenty workdays in 2017 were selected (24.04.2017-19.05.2017). Data for a set of six families of trains during AM and PM peak hours were filtered to obtain comparable results, covering regional and long-distance services (IR and IC trains, S-Bahn trains).

Figure 5 shows the layout of the study area on platform 3/4 which has an average width of about 8.7 m. The narrow zones near the ramp and the staircase have an average width of 2.3 meter (distance between obstacle and platform's edge) — 3.3 meters in the case of the staircase (side track 3). SBB selected this section of the platform with the specific aim to analyse pedestrian flows near physical obstacles (ramps and staircases) where the concentration of waiting (boarding) passengers is usually high since they tend to wait close to the platform accesses, as reported into different research studies [25–27]. In this research the section was subdivided in two main areas: a free area without obstacles, and an area with short and long obstacles (i.e., the staircase and the ramp). A third area, i.e., the area with small obstacles (e.g., recycle bins, pillars, etc.) in the right side of the section, was also investigated, but the results were not significant and therefore not considered in this work.

3. Results and Discussion

The current study selected 744 train doors for analysis, but several cases could not be used as no boarding clusters could be detected, thus leading to a final sample size of 566 cases. When comparing the selected cases with the cases without clusters, no significant results were found on the number of boarding/alighting passengers, train delays, and other variables.

Small differences can be observed on the density of the clusters and their duration between the scenarios with and without obstacles. The average density is approximately 1.11 and 1.09 person per square meter, respectively (Figure 6(a)). The average duration is approximately 22 and 25 seconds, respectively (Figure 6(b)). This result is somewhat skewed towards higher durations and it was observed that the worst situations, i.e., the situations with big clusters/queues, did not necessarily lead to higher boarding times, as stated by Harris [28].

The average and the median of the number of passengers in the cluster are 7.5 and 7, respectively. The distribution of the variable is skewed towards bigger clusters, but only a few observations with more than 22 passengers could be registered. These last cases are not relevant because they were detected when the train's door was near the entrance of the staircase/ramp, thus also considering those passengers waiting at the access for the next train (overlapping flows).

Passengers in the clusters could be subdivided in three categories (Figure 7): boarding passengers, nonboarding passengers (i.e., passengers waiting to get on the next train) and passing-by passengers (i.e., passengers who pass by the cluster and can not be defined as either boarding or nonboarding passengers). The number of nonboarding passengers grows with the number of passengers in the cluster. This could be explained by the fact that big clusters tend to include passengers who belong to other queues or who are waiting for the

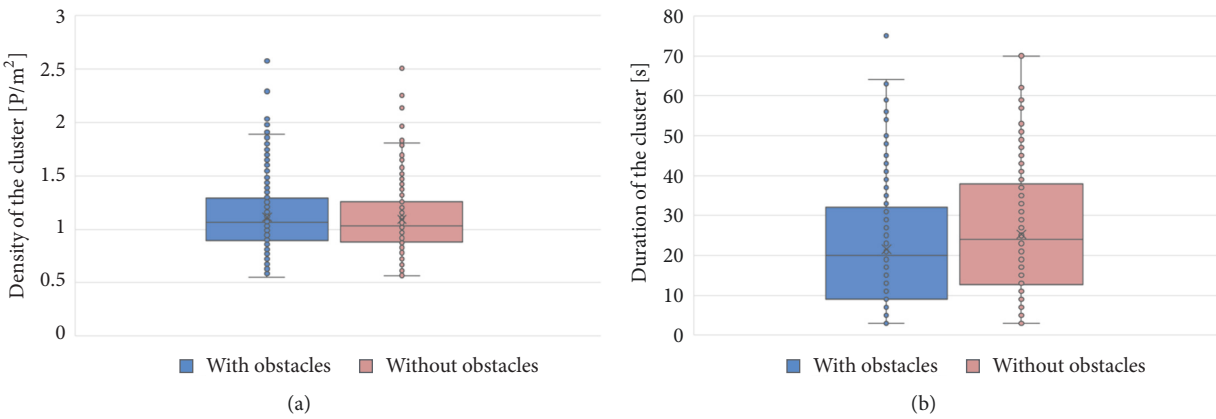

Figure 6: Box plots of the duration (a) and the density (b) of the clusters, analysing the cases with and without obstacles.

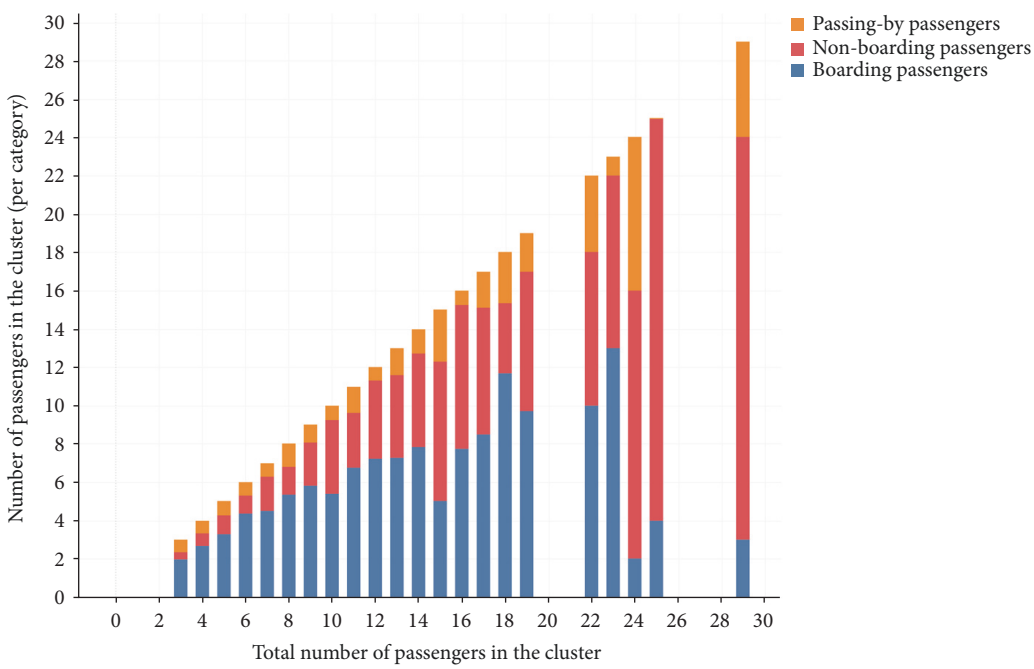

Figure 7: Distribution of passengers' categories in the cluster accordingly to the total number of passengers in the cluster.

next train. The number of passing-by passengers is relatively constant and confirms the statement that passengers select the nearest door when the train is approaching and wait to board avoiding using alternative routes [29, 30].

No significant correlation was found between the number of passengers and the number of boarding and alighting passengers (total sum), while investigating other variables, such as the average speed of passengers in the clusters and the delay of trains.

3.1. Passenger Density of Boarding Clusters. Statistically no significant difference was found when analysing the passenger density and the number of passengers of boarding clusters for both cases (with or without obstacles). As shown in Figure 8, the noise is big, although the density has a downward trend and is even lower for big clusters. The empirical assumptions of the Swiss model can therefore not be validated by looking at boarding passengers' behaviour at platform 3/4 in Bern. This result partly contradicts the available literature on the topic, where it is proven that the density is higher when boarding clusters are bigger [31]. However, they are consistent with recent studies which state that the density decreases when the passenger load increases, due to a "crowding effect" which encourages passengers to spread themselves out along the platform to avoid congestion zones [7, 30].

A possible explanation of this result is that the algorithm to detect the boarding clusters is based on the shape of the cluster and not on its density. Big clusters are therefore not necessarily the clusters with highest density. The following assumptions can help in the interpretation of the data and in further analysis. Firstly, the number of nonboarding

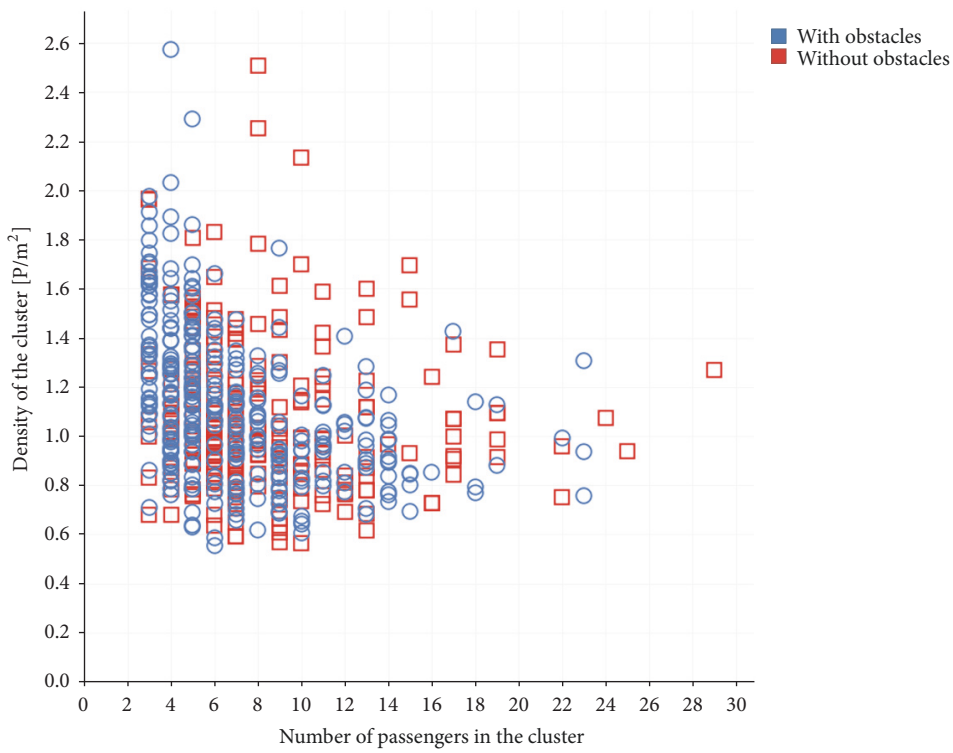

Figure 8: Correlation plot between passenger density (y-axis) and number of passengers in the cluster (x-axis) according to the presence of obstacles.

passengers, which grows with the number of passengers in the clusters (Figure 7), could bias the results in the case of big clusters where the density tends to be lower. Secondly, with a high number of passengers at the platforms, the identification of big stable clusters is difficult and results are more reliable in the case of small clusters, where the measured density was indeed higher. Thirdly, the very definition of boarding clusters, namely the MBHB approach, could affect results, since passengers who are relatively further away from the cluster (queue) can also be included, thus leading to lower density values.

3.2. Width and Length of Boarding Clusters. Figure 9 shows the correlation between the width (y-axis) and the length (x-axis) of boarding clusters according to the presence of obstacles and the dimension of the clusters. The correlation tends to be linear, although the explanatory power of a linear model shows a low R-square value (< 0.6). The presence of obstacles influences the width of the clusters, since the width is shorter as in the cases without obstacles. The obstacles indirectly force boarding passengers to build a real queue, as expected. In any case, obstacles do not affect the growing rate (0.17) of the model, since results are similar in the cases without obstacles.

The main finding is that the expected rate of 3:1 can not be validated, since the analysis led to a rate of 6:1 between the length and width of clusters. The queue grows in the longitudinal direction faster as predicted, independent from the presence of obstacles. This is more evident in case of big clusters compared to smaller ones, where rates of 1:1 were also detected, meaning that the linear model better represents the behaviour of boarding passengers when clusters are not small.

No significant results were found when investigating the distance of train doors from the access as well as the local position of clusters (i.e., right or left side).

3.3. Width and Number of Passengers in the Clusters. Figure 10 shows the correlation between the width of the cluster (y-axis) and the number of passengers in the cluster (x-axis) according to the presence of obstacles. The plot shows a large scatter that prevents an acceptable fitting (R-square value < 0.7); however, the width increases when the clusters become bigger, yet the growing rate tends to be lower, suggesting a logarithmic trend. The presence of the obstacle influences the width of the clusters, as was expected, but the difference between the regression curves is less than one meter.

The main finding is that the growth curves rise quickly when clusters are still small, i.e., at the beginning of the boarding/alighting activity, and the marginal growth is then small when clusters become bigger. A possible explanation is that when the cluster is small, boarding passengers tend to wait closer to the door, using all available space, and when the clusters are bigger, they tend to build a real queue aligning in the longitudinal direction of the platform. Pedestrians apply an optimised behavioural strategy and, as the clusters become bigger and bigger, they give rise to self-organisation flow patterns (i.e., queue formation), as observed by Helbing [32].

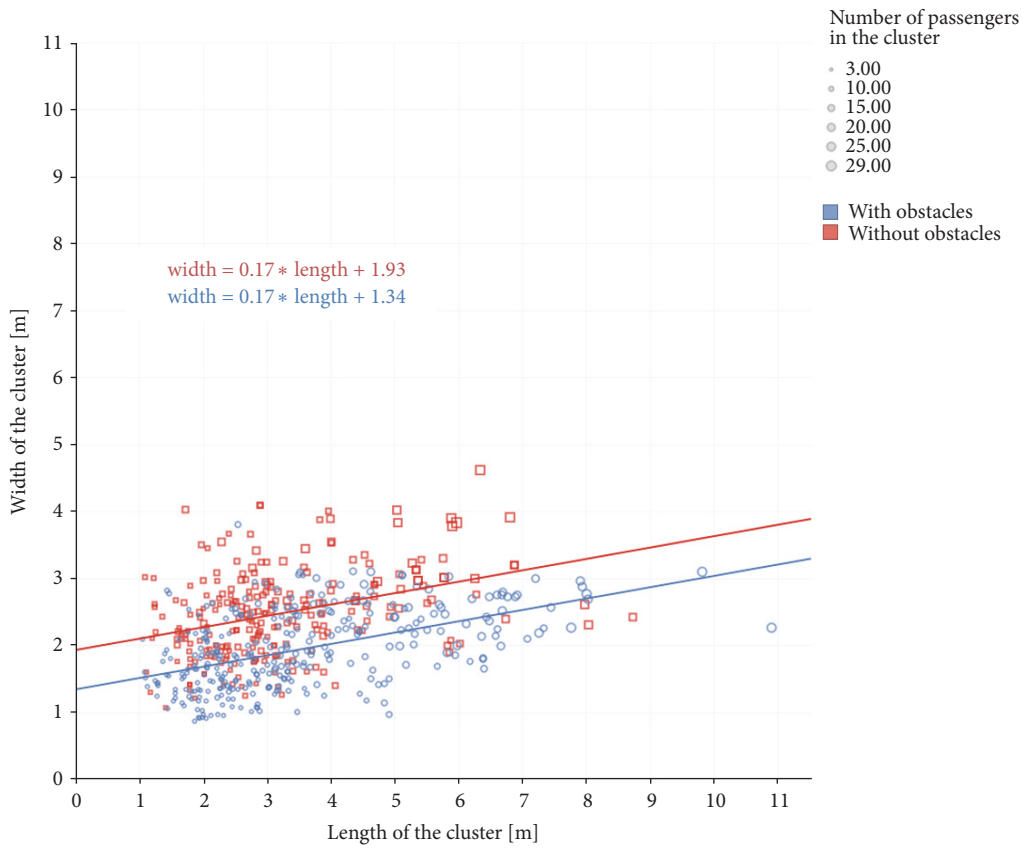

Figure 9: Correlation plot between the width (y-axis) and the length (x-axis) of the clusters according to the presence of obstacles and the dimension of the clusters.

Results are in line with previous research on passenger behaviour [1], since the most used space is between 1/3 and 2/3 of the platform width. In the situation without obstacles it is between 1.5 and 3 meters, while in the situation with obstacles it is between 0.7 and 1.5, allowing a narrow channel for alighting passenger flows.

4. Conclusions

The analysis of boarding passengers' behaviour at railway platforms is an important factor in an effort to improve the boarding/alighting process and to optimise dwell time and, consequently, the system's performance. A deep insight in boarding behaviour is required to obtain a better management of multidirectional flows (queuing) and operational issues (dwell process).

The research presented in this paper aims to advance the understanding of this topic by introducing a more comprehensive approach to model the passengers' behaviour when boarding at railway platforms. Data analysis at platform 3/4 in Bern shows that the Swiss model [15] could not be applied for situations where the distance between the platform's edge and the first obstacle on the platform is greater than 2.0 meters. The model tends to overestimate the density in the clusters, since in Bern the average observed value of the density was 1.0 person per square meter. Furthermore, the growing rate of 3:1 could not be validated, since clusters (queues) grow faster in Bern with a rate of 6:1.

The study provides additional research material in the exploration of pedestrian dynamics when boarding/alighting at wide railway platforms, i.e., an attempt to depict boarding movement with a mathematical approach. It is acknowledged that the methodological approach presents some limitations, confirming that more attention should be paid to the investigation of this research topic to provide decision makers with consistent scientific information. Different variables were not included: aspects of the physical environment (e.g., train door width), flow characteristics (e.g., longitudinal circulation, presence of luggage, people with reduced mobility) as well as local conditions (e.g., hot spots near the obstacles, delays on the network).

Further research is needed to extend the validation of the model. The results of this investigation will be compared with field data collected at other Swiss train stations (Lenzburg, Zürich Hardbrücke), considering critical pedestrian densities which occur at specific hot spots near obstacles and in congested environments.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

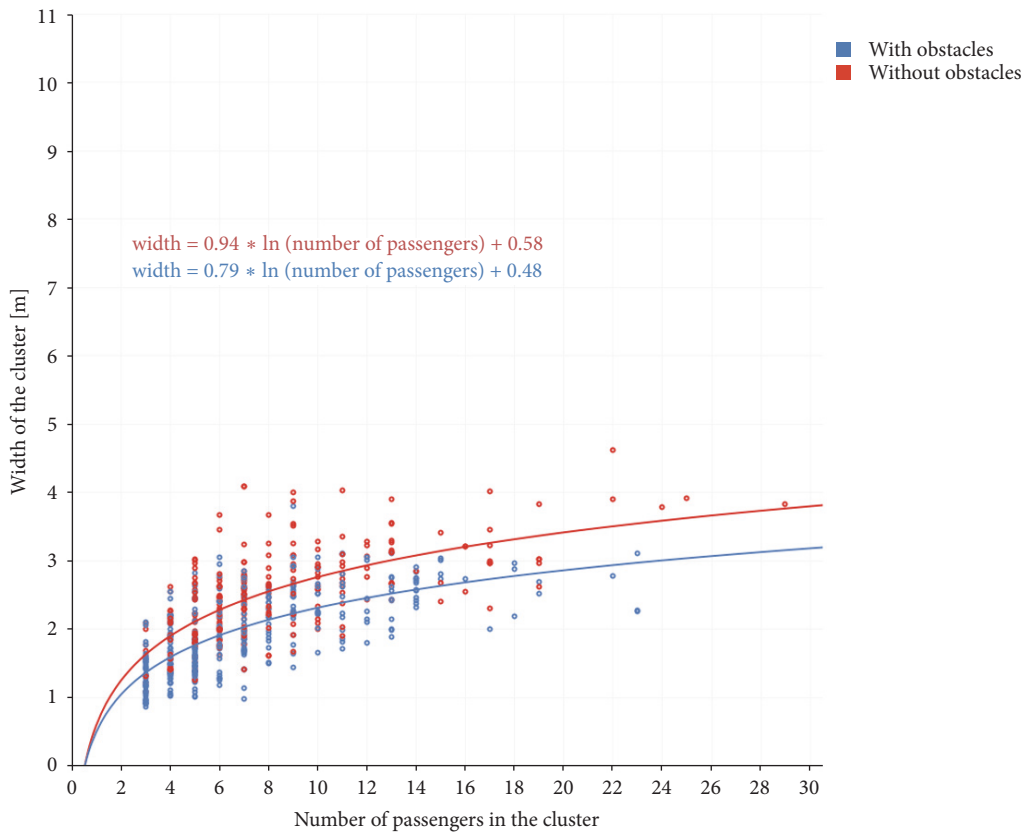

Figure 10: Correlation plot between the width of the clusters (y-axis) and the number of passengers in the clusters (x-axis) according to the presence of obstacles.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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