Modelling passenger distribution and interaction on platform train interfaces

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ABSTRACT

Platform edge doors (PEDs) are now common in metro stations, however it is not clear what their effect is in the distribution and interaction of passengers in the platform train interface (PTI). This study proposed a new area of the platform defined as platform conflict area (PCA), which included the PTI and the relevant space on the platform in front of PEDs. The method consisted on a carriage design to simulate typical boarding and alighting behavior at University College London's Pedestrian Accessibility Movement Environmental Laboratory (PAMELA), in which the PCA was divided into semi-circular layers that originated at the PEDs. The interaction time (IT) was adjusted and a multinomial distribution function was used to model passengers based on London Underground stations. When the ratio (R) between passengers boarding and alighting was equal to 4, passengers started to board earlier, reaching 38% less IT than the case or R = 0.25 and half the time of R = 1. The distribution model presented no significant differences between the expect and observed data. Further research needs to be conducted to calibrate the coefficient to more accurately predict the IT and verify the assumed multinomial distribution model to determinate the maximum number of passengers waiting to board in each layer on the PCA considering different types of stations.

Keywords: Pedestrian, Platform edge doors, Platform train interface, Distribution, Interaction time.

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1. INTRODUCTION

In order to optimize the design and operation of new and existing metro stations a detailed understanding of how passengers behave in different spaces is needed. Seriani and Fernandez (2015) found that passengers in metro stations can be studied in at least five spaces: platform train interface, platform-stairs, concourse, complementary (e.g. commerce), and the city (i.e. boundary to the station). Each of these spaces needs its own, in-depth level of analysis. In this study we focus on the first space, in which the most complex behavior take place, i.e. boarding and alighting.

There are a number of factors which influence the behavior of passengers in the platform train interface (PTI) and these can be classified into 4 types: physical (e.g. luggage), information (e.g. maps), environment (e.g. weather), and people (e.g. density on the platform) (RSSB, 2008). In this study we focus on factors related to people in situations where a high density of passengers who are boarding and alighting were reached. Specifically, we investigate how these competing groups of passengers interact and move to avoid collision.

Platform edge doors (PEDs) have been used in a variety of metro stations worldwide (Kyriakidis et al., 2012). PEDs at London Underground (LU) work simultaneously with the trains doors as sliding barriers between the platform and the train to improve safety and comfort conditions for passengers on PTI (Kroes et al., 2014; De Ana Rodriguez et al., 2016). However, little research has been done to know what the effect of PEDs on the interaction is and how passengers are distributed on the platform. The hypothesis of this research is that a multinomial distribution can be used to determinate the maximum number of passengers waiting to board the train, in which a higher interaction will be reached when the distance between passengers is reduced or when the time of overlap (passengers boarding and alighting simultaneously) is increased.

It is proposed as a general objective to model the distribution and interaction of passengers boarding and alighting at metro stations when PEDs are used. The specific objectives are: a) identify the main variables that affect the interaction of passengers at London Underground (LU) stations; b) to simulate different scenarios of boarding and alighting at University College London’s Pedestrian Accessibility Movement and Environmental Laboratory (PAMELA); c) to measure and classify the interaction; d) to propose a model of distribution of passengers on the platform. The LU was used as a case study, but the results can be expanded to other public transport systems.

This paper is composed of five chapters, including this one. In Chapter 2 a summary of studies to measure the interaction time and distribution of passengers is presented. Next, in

Chapter 3 the method followed for this work is explained. Chapter 4 shows the results of the interaction measurements and the distribution of passengers. Finally, in Chapter 5 the conclusions are delivered.

2. LITERATURE REVIEW

The interaction time (IT) of passengers on the PTI is defined as the time in which the boarding and alighting is simultaneously. Therefore, the IT is related to the Passenger Service Time (PST), which is defined as the time that the train remains stopped at the platform transferring passengers (TRB, 2000). The literature on the PST is profuse, mainly with respect to linear and non-linear models. It is not our objective to make a review of all the models, just to mention the main contributions to the Highway Capacity Manual (HCM) (TRB, 2000; TRB, 2003) which are necessary for background to this paper. The first type is the well-known linear PST model based on the time for opening and closing doors (t_{oc}), the average time it takes each passenger to board (t_b) and alight (t_a), and the number of passenger boarding (p_b) and alighting (p_a) (see Equation 1). In this equation the IT is not an explicit variable and therefore it should be calculated manually using videos or any other technique.

$$PST = t_{oc} + t_b \cdot p_b + t_a \cdot p_a \tag{1}$$

The second type is the non-linear models, in which the PST (see Equation 2) is defined as a function of different variables such as: number of doors per car (D), door width factor (DWF), number of passenger boarding (B), number of passenger alighting (A), peak door factor (F), number of through passengers (T), and number of seats per carriage (S). The model reported in Harris (2006) is based on previous LU Train Service Models reported in Weston (1989) and Harris (1994), in which the IT (in seconds) is calculated for the busiest door using β = 0.027 (see Equation 3).

$$PST = 15 + \left[1.4 \cdot \left(1 + \frac{F}{35}\right) \cdot \left(\frac{T-S}{D}\right)\right] \cdot \left[\left(F \cdot \frac{B}{D}\right)^{0.7} + \left(F \cdot \frac{A}{D}\right)^{0.7} + 0.027 \cdot \left(F \cdot \frac{B}{D}\right) \cdot \left(F \cdot \frac{A}{D}\right)\right] \cdot DWF \tag{2}$$

$$IT = \beta \cdot B \cdot A \tag{3}$$

Other authors (Wiggenraad, 2001; Heinz, 2003; Harris, 2006) have studied the PST empirically based on surveys and behavior observation at Dutch and LU stations. The authors found that the PST depends on the vertical gap, horizontal gap, number of doors, number of seats per car, distribution of passengers on the platform, and use of luggage. However, only Harris (2006) measured the IT using Equation 3. The author found that the formula was not representative of high-density situations, therefore he proposed a value of β = 0.011 (reported in Rosser, 2000) instead of 0.027 which is more representative, but still did not show if there was a maximum or dynamic value of the interaction time in presence of PEDs.

In addition, the PST has been studied in laboratory experiments (Daamen et al., 2008; Fujiyama et al., 2014; Fernandez et al., 2015), in which wider doors and small vertical gaps increased the flow and therefore can reduce PST. Recently, De Ana Rodriguez et al. (2016) studied the effect of platform edge doors (PEDs) on the PST. This was the first study to be conducted in this area and helped to give evidence to the arguments surrounding the effect of PEDs on passenger flows. Did PEDs increase PST (by increasing passenger board/alight time due to needing to step through a double door), or did it improve PST as passengers would know exactly where the train doors would open and therefore organize themselves more efficiently on the platform. It was found that the use of PEDs had no relevant impact on the PST despite the behaviors of passengers being improved (i.e. the time to complete boarding and alighting was unaltered but occurred in a more orderly fashion). However, the authors only studied the PST, and did not determine the effect of PEDs in the IT.

In relation to the distribution of passengers, Wu and Ma (2013) reported that the use of PEDs changed the way passengers stand on the platform. However, the modelling of passenger interactions at the PTI are in need of greater refinement if we are to understand the complex nature of people’s movements and the elements of the environment. For example, crowd density guidelines are often quoted as an average number; TRB (2000) define a dense station as one in with walkways on average reached 2.17 passengers per meter square or more. However, other researchers (Lam et al., 1999; Kim et al., 2015) have studied crowd densities, in which the path choice of passengers is a function of the stress, availability of seats, sexual harassment, and discomfort due to congestion on platforms. Therefore, an average density may not be the most useful for optimizing passenger flows in the PTI.

A detailed model of crowd density on the platform has been conducted by Krstanoski (2014) in which boarding and alighting are represented with a multinomial distribution and depend on various factors such as the position of the exit gate in the destination station, density inside the car, how crowded the platform is, if there are marking of the door’s position on the platform, and random variables (e.g. meeting with friend). The multinomial distribution of Krstanoski (2014) considered the boarding/alighting stable over the time for each door on the platform and a high-density situation is reached in the whole platform. This assumption could be expanded to the interaction on the PTI when the ratio between the number of passengers boarding and alighting (R) do not changes over time in front of the most crowded door (or critical door for the system).

The use of PEDs and other design recommendations in the PTI (LUL, 2012) can be modelled and compared to design thresholds. One of the most common indicators to represent the degree of congestion and conflict in metro stations is the Level of Service or LOS (Fruin, 1971), which represent walkways in a range from a level A (free flow or density lower than 0.31 pass/m^2) to level F (over the capacity or more than 2.17 pass/m^2). However, this index is used in small spaces based on the overall density, which is defined as the number of passengers per physical space (e.g. total number of pedestrians on the whole platform). Therefore, identification cannot be made of which part of the space is more congested or where the highest interaction of pedestrians at metro stations would be if the layout of the train is changed (Evans and Wener, 2007). In addition, there is not a clear classification for high-density situations in walkways (i.e. what happens when there is more than 2.17 pass/m^2?). In the case of LU, in our previous study (Seriani et al., 2016) we proposed the Level of Interaction (LOI) as a new indicator when PEDs are installed in the PTI. The LOI was influenced by the types of queues, formation of lanes, density by layer and distance between passengers in a new space defined as platform conflict area (PCA). When the ratio (number of passengers boarding divided by the number of passenger alighting) was high, then the LOI reached a greater value.

Despite the wide variety of research conducted to aid understanding and optimization of platform design both for safety and service delivery, further studies are needed to inform how passengers interact on the platform, specifically when PEDS have been introduced. We extend the analysis of De Ana Rodriguez et al. (2016) to produce a new model of interaction at the PCA, which we hope will help operators further optimize service both for when PEDs are present.

3. METHOD

The method for this research consisted of four steps. First, the typical pattern of movement of passengers was identified in London Underground (LU) stations. To that end, Westminster Station (WMS) was chosen as a case to study. This station belongs to the Jubilee line and is an important interchange in the metro network. In WMS platform edge doors (PEDs) are installed between the train and the platform. This station was part of a complete CCTV video recording study solicited by London Underground Limited (LUL) in collaboration with the members of PAMELA. Variables at WMS were classified into three types according to Seriani and Fernandez (2015). During this study, we consider physical (e.g. platform width) and spatial (e.g. number of seats) variables fixed, while the operational variables (e.g. number of passengers boarding and alighting) varied during the experiments. The operational variables at WMS were recorded during the most congested hour of the day (8:15 to 9:15 am), reaching a flow of 30 train/h. To obtain the interaction time a total number of trains observed was 90, equivalent to three days of analysis. While for the distribution of passengers waiting to board the train, a total of 2 weeks were recorded. In both cases, videos were from

November 2015. The analysis was conducted using Observer XT 11 software, prior to analysis the videos were converted into .avi format.

Second, the mock-up carriage was configured and assembled at PAMELA with a set of parameters to represent the new generation of London Underground trains. This replicated the same physical and spatial variables as in WMS, i.e. 2 double 1600 mm wide doors, 20 seats, a horizontal gap between train and platform of 90 mm, and a vertical gap of 0 mm. This produced a total floor area inside the carriage of 17.46 m^2, which allow a capacity of 90 passengers (for a density of 4.0 pass/m^2, used in static modelling for capacity at metro stations in LUL, 2012). The platform was 10.00-m long and 3.30-m wide.

Third, three loading (flow) conditions were simulated in this mock-up based on a preliminary analysis of CCTV footage from 2 doors at WMS (see Table 1). The LC_0 and LC_1 loads were only tested to warm up passengers for each day and to check initial values or boundaries of the experiment when there were no passengers in the train or on the platform. In the case of LC_5 this scenario was used to calculate the total load of the train. As there was limited space at PAMELA to simulate the behaviour of each passenger, the analysis focused on the period between the train doors opening and closing (i.e. after the train arrived).

Load Condition code	**Board per door**	**Alight per door**	**On-board per door**	**Ratio (boarding/alighting)**	**Number of runs / scenario**
LC_0	55	0	0	-	2
LC_1	0	55	0	-	2
LC_2	40	10	5	4	10
LC_3	10	40	5	0.25	10
LC_4	20	20	15	1	10
LC_5	110 +crush	0	0	-	10

Table 1 – Loads used in the experiment at PAMELA

Fourth, to study the distribution and interaction between passengers boarding and alighting at PAMELA it was used the space defined in our previous study (Seriani et al., 2016) as platform conflict area (PCA). The PCA included the PTI and the relevant portion of the platform in front of the PEDs, in which the space was represented as a semi-circular space divided by layers of 0.50 m each (see Fig. 1 and Fig. 2), equivalent to the body depth of passengers defined in Fruin (1971). The radius L represents the influence of the door. In addition, it was used the Level of Interaction (LOI) (Seriani et al., 2016) based on the types of queues, formation of lanes, density by layer (number of passengers boarding and alighting in each layer divided by the area of each layer), and distance between passengers. The distribution of passengers on the PCA was obtained by the position (x, y) of each person using Petrack software (version 0.8) as a tracking tool (Boltes and Seyfried, 2013), in which videos from cameras located 4.0 m height from the floor in PAMELA were analysed. While the interaction time (IT) was measured using the recording from the video cameras.

Fig. 1 – Example of PCA at PAMELA experiments

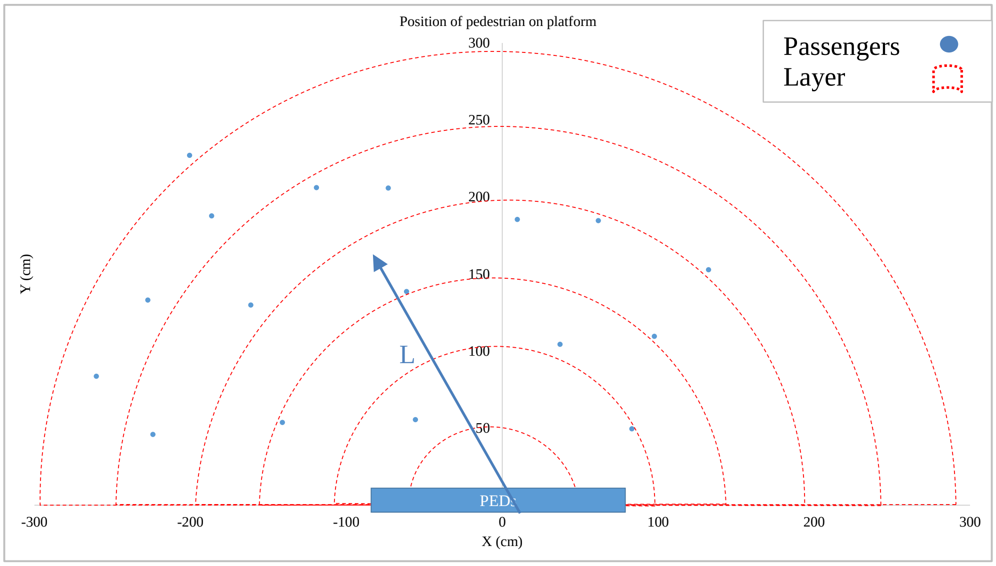

Fig. 2 – PCA divided in layers of 50 cm each to measure interaction on the platform

4. RESULTS

4.1 Characteristics of passengers

For the experiment, we recruited 110 participants to form 11 groups of 10 passengers each. Participants were 46% men and 54% women, 78% of them were regular users of the London Underground and mostly were under 45 years old. The total passenger load tested in the scenario LC_0 and LC_1 was 8221 kg (including seated passengers). The average height of passengers was 170 cm with a deviation standard of 8 cm. In addition, boarding passengers used red hats and alighting passengers used white hats and each set of 10 passengers wore different coloured bibs and each passenger had a unique number on their bib. Therefore, each passenger was identified by their bib colour, hat colour and number. This produced an input density on the platform of 3.3 pass/m^2 and 5.15 pass/m^2 inside the car. To make sure passengers walk "naturally" as if they were boarding and alighting in the LU, randomly groups were chosen to board, alight or remain inside the carriage.

4.2 Interaction of passengers on the PCA

Three types of interaction were identified between opening and closing of PEDs: only alighting (when boarding passengers were waiting on the platform), overlap (when boarding and alighting occurred simultaneously), and only boarding (before the PEDs opened and when alighting was complete).

The first (only alighting) and second (only boarding) type of interaction were measured at WMS. It can be concluded that when the number of boarding (40 pass) divided by that of alighting (10 pass) was high (R = 4) most passengers were waiting in front of the doors, this resulted in high interaction and alighting passengers formed a narrow single lane. When R = 0.25 passengers queuing occurred at the sides of the doors resulting in a low interaction and the formation of two lanes for alighting passengers. When R = 1 the behavior of passengers was in between the two cases R=4 and R=0.25 (more explanation on the effect of PEDs in the behavior can be found in De Ana Rodriguez et al., 2016).

The first two types of interaction were also observed at PAMELA experiments. In addition, the average maximum density by layer (k) was obtained at the laboratory experiment before/after the doors opened. After the doors opened, k followed a logarithm distribution with a coefficient of correlation between 0.97 and 0.99 (see Equation 4 and Table 2). This means that the interaction was higher near the PEDs and decreased as the distance from the PEDs increased. K was more representative to measure interaction than the overall density which is used in the Level of Service – LOS (Fruin, 1971), reaching up to four times more density when R = 4 (see Table 3). More explanation of k can be found in Seriani et al. (2016).

$$k = -C_1 \cdot \ln(x) + C_2 \quad \text{for x = distance from the PEDs [cm]} \qquad (4)$$

R (boarding/alighting)	C1	C2
4.0	3.56	6.75
1.0	3.43	6.21
0.25	3.06	5.44

Table 2 – Coefficients in the interaction model of density by layer on the PCA after the doors opened at PAMELA

R (board/ alight)	Before PEDs opened		After PEDs opened	
	Max. Overall* (pass/m^2)	**Max. k (pass/m^2)**	**Max. Overall* (pass/m^2)**	**Max. k (pass/m^2)**
4.0	1.34 (LOS E)	1.40 (LOS E)	1.82 (LOS E)	7.64 (LOS F)
1.0	0.91 (LOS D)	1.10 (LOS E)	1.30 (LOS E)	6.62 (LOS F)
0.25	0.35 (LOS B)	0.63 (LOS C)	0.99 (LOS D)	5.60 (LOS F)
*Considering the PCA as a rectangular space of 15 m^2 without layers				

Table 3 – Difference between maximum overall density (rectangular space) and density by layer (semi-circular space) on the PCA at PAMELA

Before the PEDs opened passenger were more concentrated in the middle of the platform at PAMELA. The results are supported in Fig. 3, in which the maximum density by layer on the PCA is obtained just before the PEDs started to open. When R = 4 a high value was presented on average compared to R = 0.25 and R = 1, due to the higher number of passenger boarding, reaching a maximum of 1.4 pass/m^2 (LOS = E using Fruin, 1971) in the fourth layer (150 – 200 cm). The first layer (0 – 50 cm) was unused because boarding passengers respected the yellow line for safety reasons.

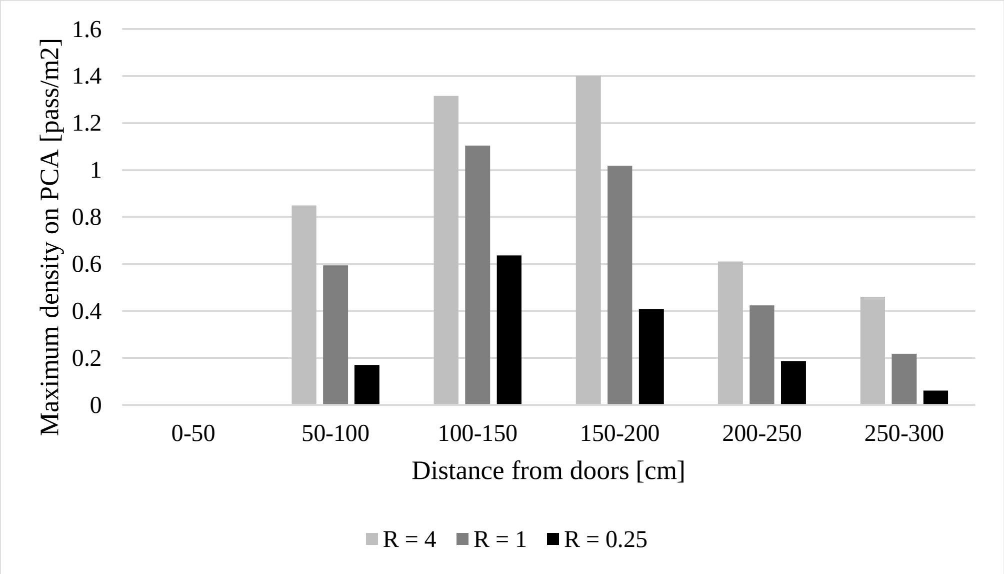

Fig. 3 – Average maximum k on the PCA just before PEDs opened at PAMELA

With respect to the third type of interaction (boarding and alighting simultaneously), Table 4 shows the results of the IT observed from the videos at PAMELA experiments. The IT was measured only in the PTI when boarding and alighting was simultaneously conducted (bidirectional flow), considering the difference in time between the last passenger to alight and the first passenger to board. If the first passenger boarded after the last passenger alighted, then the IT was equal to zero. When the ratio between boarding and alighting (R) was equal to 4 the average IT reached was 3.29 s which was 38% lower than the case of R = 0.25 and almost 50% lower that the case of R = 1. However, when R = 4 passengers started to board earlier (segment 10th s) than in the case of R = 0.25 (segment 30th s) and R = 1 (segment 15th s). This was caused because in the case of R = 4 there was lower number of passenger alighting (10 passengers) compared to the cases of R = 0.25 (40 passengers alighting) and R = 1 (20 passengers alighting).

R (board/ alight)	**IT$_{exp}$ (s) at PAMELA**		**IT (s) using Eq. (3) in Harris (2006)**		**Diff.***	**β$_{PEDs}$**
	Average	Std. dev.	Average	Std. dev.		
4.0	3.29	3.98	10.07	1.88	-6.78	0.0095
1.0	7.55	6.02	11.45	1.76	-3.90	0.0177
0.25	4.57	4.10	11.81	1.66	-7.24	0.0104
* Is obtained by subtracting the IT from PAMELA and IT from Harris's method						

Table 4 – Interaction time between passengers boarding and alighting at PAMELA

The results of the IT are different compared to the LOI defined in Seriani et al. (2016), reaching a high IT when R = 1, a medium IT when R = 0.25, and a low IT when R = 4. In addition, Table 4 shows that the IT obtained with the Equation (3) reported in Harris (2006) did not match the values of IT obtained from the PAMELA experiments, reaching up to 7.24 s of difference in the case when R = 0.25. This mean that the method reported in Harris (2006) needs to be adjusted for the case with PEDs by including the behavior of passengers when PEDs are used in the PTI. To solve this, a new value of β_{PEDs} was obtained by dividing the IT observed at the experiments by the multiplication between the number of passengers boarding and alighting for each scenario (Equation 5).

$$\beta_{PEDs} = \frac{IT_{exp}}{(B \cdot A)_{exp}} \tag{5}$$

With the new coefficients β_{PEDs}, the IT was predicted at WMS using Equation (6). From the videos at WMS the average number of passengers boarding (B) was equal to 11 and the average number of passengers alighting (A) was equal to 12. Therefore, the ratio between boarding and alighting (R) was almost equal to 1. According to Table 4 the value of β_1 is equal to 0.0177 when R = 1. As a result of using Equation (6), the predicted IT at WMS was equal to 2.55 s, however from the videos observed at WMS the real IT showed an average value equal to 1.09 s (standard deviation of 1.84 s). This value is almost half of the predicted IT, but still the predicted IT should be considered a better approximation compared to the IT = 3.88 s calculated for WMS using the Equation (3) (reported in Harris (2006) with a β = 0.027), which is almost four times the real IT. The new values of β_{PEDs} in Table 4 are similar to β = 0.011 for high-density situations reported in Rosser (2000) and therefore should be considered more representative of the interaction between passengers boarding and alighting.

$$IT_{Predicted} = \beta_{PEDs} \cdot (B \cdot A)_{WES} \qquad (6)$$

4.3 Distribution of passengers on the PCA

The maximum number of passengers waiting to board (i.e. before PEDs opened) in each layer was calculated (see Table 5) in a sample size of s = 10 (total number of runs per scenario) at PAMELA. Considering that the number of passengers boarding appear to be stable over the time for each value of R, then the distribution of passengers in each layer can be modelled using multinomial distribution. To this objective, let us denote the maximum number of passengers waiting to board (b) in layer j with b_j. The sum of b_j for all layers will be equal to B, which is the total maximum number of passenger waiting to board on the PCA. The conditional probability that there are b_1 in layer 1 (X_1),…, b_n in layer n (X_n), with probabilities p_1,…, p_j is given by the following, in which $E(X_j)$ is the mean and $Var(X_j)$ is the variance.

$$P(X_1 = b_1, \dots, X_n = b_n) = \frac{B!}{b_1! \cdots b_n!} \cdot p_1^{b_1} \cdots p_n^{b_n} \qquad (7)$$

$$\textstyle\sum_j^n b_j = B \quad \text{and} \quad \sum_j^n p_j = 1 \qquad (8)$$

$$E(X_j) = B \cdot p_j \quad \text{and} \quad Var(X_j) = B \cdot p_j \cdot (1 - p_j) \quad \text{for j = 1, …, n} \qquad (9)$$

Similar to the method proposed by Krstanoski (2014), in which the authors used the Maximum Likelihood Estimates (MLE) (Cox, 1984) to obtain the probability of passengers boarding and alighting in a specific door on the platform, in this study it was used the MLE of probabilities p_j from Equation (7) to obtain the probability of the maximum number of passengers waiting to board in each layer on the PCA at PAMELA. As a result the MLE multinomial probabilities ($\widehat{p_j}$) is defined in Equation (10) and the results are presented in Table 5.

$$\widehat{p_j} = \frac{\sum_{i=1}^{s} b_{j,i}}{\sum_{i=1}^{s} \sum_{j=1}^{n} b_{j,i}} \quad \text{for j = 1, …, n and i = 1,…, s} \qquad (10)$$

Using the Equation (9) the mean and standard deviation (square root of the variance) of the maximum number of passengers waiting to board in each layer at WMS can be predicted and compared to the data from PAMELA experiments. From the videos at WMS, B on the PCA was equal to 11 pass. This value was obtained for each segment of 5 s. In addition, from the videos at WMS the ratio between boarding and alighting (R) was equal to 1. Therefore, the $\widehat{p_j}$ values can be obtained from Table 5 when R = 1. The results of the mean and standard deviation are presented in Fig. 4, in which the difference of passengers waiting to board in each layer (b) reached 1 passenger compared to the observed data at WMS. A chi-square test was performed with a significant level of α = 0.05. The null hypothesis H_0 was defined as when there are no difference between the expected and observed values. The result of the chi-square test showed a p-value higher than 0.05, which mean that the hypothesis is accepted and there are no significant differences between the expected and observed data at WMS.

R (board/ alight)	Run	0-50	50-100	100-150	150-200	200-250	250-300
4.0	1	0	2	2	4	5	3
	2	0	2	3	6	2	5
	3	0	1	4	6	5	2
	4	0	0	1	4	2	6
	5	0	2	2	6	4	3
	6	0	1	3	6	3	5
	7	0	1	4	5	3	3
	8	0	1	4	6	5	4
	9	0	0	4	5	4	4
	10	0	0	4	7	3	3
	$\widehat{p_J}$	0	0.058	0.182	0.323	0.211	0.223
1.0	1	0	0	5	6	3	0
	2	0	1	1	1	2	3
	3	0	1	1	4	2	2
	4	0	0	3	4	2	3
	5	0	0	3	5	2	3
	6	0	1	1	3	4	2
	7	0	1	3	4	3	3
	8	0	2	3	3	2	1
	9	0	1	2	6	2	0
	10	0	0	4	4	3	1
	$\widehat{p_J}$	0	0.060	0.224	0.344	0.215	0.155
0.25	1	0	1	2	1	0	0
	2	0	1	1	1	1	0
	3	0	0	1	2	0	0
	4	0	0	1	1	1	1
	5	0	0	3	0	1	1
	6	0	0	1	1	2	0
	7	0	0	1	2	3	0
	8	0	0	1	3	0	1
	9	0	0	2	3	1	1
	10	0	0	2	2	2	1
	$\widehat{p_J}$	0	0.040	0.306	0.326	0.224	0.102

Table 5 – Maximum number of passengers waiting to board on the PCA with PEDs at PAMELA

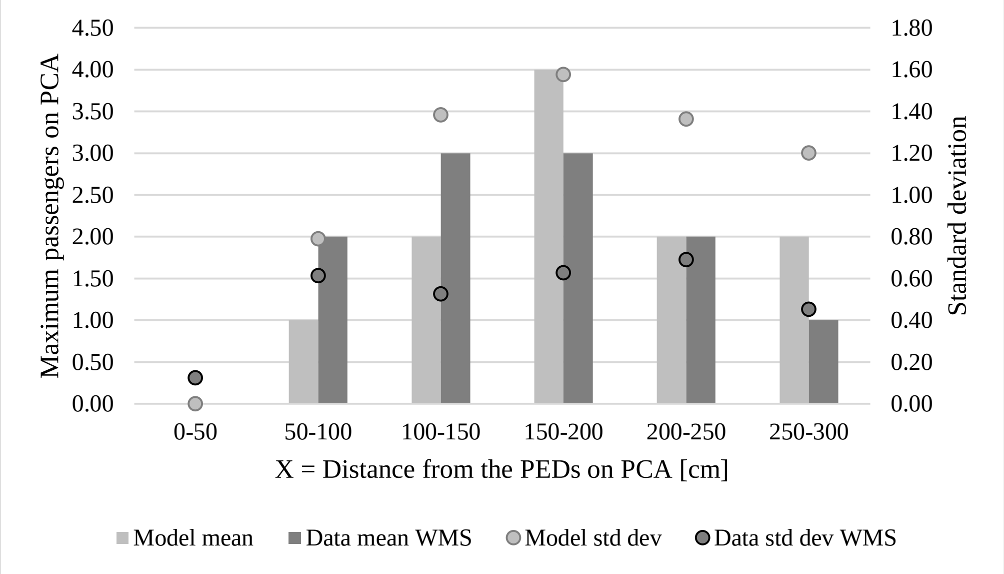

Fig. 4 – Predicted maximum number of passengers waiting to board at WMS using the distribution model compared to the data observed at WMS

Because of the sample size (only 10 runs each scenario) it was not possible to have an rigorous statistical analysis (Thompson, 1987) to obtain the parameters of the multinomial distribution, however this do not mean that this distribution model is not accurate, but still can predict the variable b_j for each layer j. Although, to reduce the differences between the model and the data more experiments should be done at PAMELA focused on the calibration of $\widehat{p_j}$ for different demand of passengers even if the ratio between passengers boarding and alighting remain constant over the time. In addition, further research is needed to validate this distribution model in other London Underground stations.

5. CONCLUSIONS

This study presented a new method to model the interaction when platform edge doors (PEDs) are used. This was completed using a novel semi-circular space defined as the platform conflict area (PCA). To validate this method a mock-up was used at the University College London's Pedestrian Accessibility Movement Environmental Laboratory (PAMELA) and observations were recorded at Westminster Station (WMS) using CCTV system. Results were divided into three.

Firstly, the interaction was studied at WMS and PAMELA experiments as a function of the types of queues, formation of lanes, density by layer and distance between passengers. The number of alighting lanes formed increased as the ratio between boarding and alighting (R) decreased. In addition, when R was equal to 4, passengers reached a high interaction compared to the case R = 1 and R = 0.25. In particular, after the doors opened the density by layer followed a logarithmic distribution, which meant that interaction was higher near the PEDs and decreased as the distance from PEDs increased. This density was more representative than the overall density in the PCA.

Secondly, an interaction time (IT) model was calibrated to obtain the interaction between passengers boarding and alighting simultaneously when PEDs were used at PAMELA and WMS. The new coefficients of the IT model were classified for each value of R. When R was equal to 4, passengers started to board earlier at the experiments, reaching 38% less IT than the case of R = 0.25 and half the IT of R = 1. However, further research is needed to calibrate the coefficient to more accurately predict the IT in other types of stations.

Thirdly, the multinomial probability distribution was used to calculate the maximum number of passengers waiting to board (b) in each layer on the PCA (i.e. before the PEDs opened). The results of this model can be used to calculate/estimate the necessary platform width when PEDs are installed. The model seems to be more representative of the interaction typical models which consider uniform distribution of passengers on the PCA. This distribution model presented only a difference of 1 passengers between the predicted and observed data at WMS. In addition, no significant differences when obtained. Further research is needed to consider a larger sample size and calibrate the model in different types of stations.

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