Pedestrian Level of Interaction on Platform Conflict Areas by Real-scale Laboratory Experiments

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Abstract

The objective of this work was to develop a new method to measure the interaction of passengers boarding and alighting at metro stations. This method included the Level of Interaction (LOI) as more precise indicator compared to the Level of Service (LOS). The method consisted of building a mock-up of a metro car and a series of simulation experiments in University College London's Pedestrian Accessibility Movement Environmental Laboratory (PAMELA) based on observation at two London Underground station. This mock-up included platform edge doors (PEDs) and a new space defined as platform conflict area (PCA) in front of the train doors in which the density of passengers was high. Results of the laboratory experiments were expressed according to the types of queues, formation of lanes, density by layer, and distance between passengers, in which the interaction followed a logarithmic distribution and no statistical differences were found with PEDs. These results are helpful for traffic engineers and policy makers to measure the interaction and use the LOI as a new indicator for the design of spaces in metro systems. Further research needs to be conducted to measure the personal space of each passenger in the boarding and alighting process on the PCA.

Keywords: Pedestrian; interaction; platform; metro station

1. Introduction

There are different factors affecting the behaviour of passengers in metro stations (underground and over ground) (RSSB, 2008). This work used the factors related to people, in which behaviour is defined as the way that passengers interact with each other in high-density situations (more than 2.17 passengers per m^2 or Level of Service of F in Fruin (1971)) to avoid collision with other pedestrians or obstacles when the design of these spaces is changed (e.g. use of platform edge doors).

A typical design of boarding and alighting in metro stations is composed of a train door and the corresponding adjacent spaces on the platform and on the trains. This space can be named as platform-train interface (PTI) (Seriani and Fernandez, 2015a). To improve safety and energy conditions (e.g. air-condition, ventilation or fire detection) in this interface platform edge doors (PEDs) can be installed, which work as barriers between the train and the waiting passengers on the platform (Clarke and Poyner, 1994; Kyriakidis et al., 2012; Qu and Chow, 2012). Some authors (De Ana Rodriguez et al., 2016) have studied the effect of PEDs on the boarding and alighting time, but little research has been done to identify whether the use of PEDs can reduce interaction of passengers.

To reduce the interaction of passengers who are boarding and alighting the train, different design standards can been used (e.g. increase the minimum width of platforms). Some of these standards regulate station designs based on operational capacity. For instance, London Underground Limited (LUL, 2012) states that the total platform width of a station should not be less than 3.0 m (with a density of 4.0 pass/m^2 to reach capacity), but for other manuals such as NFPA-130 (2007) 1.12 m should be enough to evacuate passengers in case of a fire. In practice, compliance to these standards is tested by simulation (e.g. pedestrian models) and then compared to design thresholds (Still, 2000; Teknomo, 2006). One of the most common indicators is the Level of Service or LOS (Fruin, 1971) defined in HCM (2000), which indicates the degree of congestion and conflicts of passengers. This indicator goes from level A (density less than 0.31 pass/m^2, free flow and no conflicts) to the level F (density more than 2.17 pass/m^2, sporadic flow, frequent stops and physical contact), where E is equal to the capacity (density between 1.08 and 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 design of the PTI is changed (Evans and Wener, 2007). In addition, there is not a clear classification for high-density situations (what happens when there is more than 2.17 passengers per m^2?). Carreno et al. (2002) state that the LOS indicated by Fruin (1971) is based principally in the personal space of passengers, which is not the only factor that affects walking environments. In fact, Carreno et al. (2002) developed a new indicator called Quality of Service (QOS) for pedestrians, which was applied only at the street level.

According to Fruin (1971) a standing passenger can be represented as an ellipse of area 0.30 m^2 (body depth of 50 cm and shoulder breadth of 60 cm). In Little (1965) the personal space is defined as the area that an individual use to interact with other pedestrians and the environment, in which interaction between two pedestrians depends on the acquaintance between them. However, some authors (Hartnett et al., 1974; Sanders, 1976) found that the personal space is a function of the body height, body position, and gender. For example, Pushkarev and Zupan (1975) state that in the case of PTI where queues are formed, passengers need at least 0.74 m^2 to walk or wait to board the train, in which a "face-to-face" less than 0.5 m will be felt as intimate.

The effects of intimacy on interpersonal distance has been studied by other authors. As it is reported in Hall (1966) when two pedestrians stand closer to each other, then the interpersonal space is classified into 4 groups according to the relationship between them: a) intimate zone (< 0.5 m) when pedestrians have a special relationship; b) personal zone (0.5 – 1.2 m) when a pedestrian knows another pedestrian; c) social consultative zone (1.2 – 4.0 m) when pedestrians do not know each other but they permitted to communicate; and d) public distance (4.0 – 10.0m) when pedestrians do not know the other pedestrians. Similarly, Sommer (1969) studied the social behaviour in stations and defined the personal space according to three levels: a) intimate (< 0.5 m); b) personal (0.5 – 1.2 m); and c) Social (>3.0 m). Considering the ellipse area of 0.30 m^2 defined by Fruin (1971) the intimate level in these classifications will be reached when the distance between heads of two pedestrians is less than 0.8 m (0.5 m plus two times half the body depth), which can be considered as a critical value for social behaviour. However, recently studies (Webb and Weber, 2003; Evans and Wener, 2007) showed that the interpersonal space depends on other factors such as crowd, vision, hearing, mobility and stress level. In addition, Gérin-Lajoie et al. (2008) state that personal space is asymmetrical in shape and in side (left and right) when overtaking an obstacle. This change of interpersonal space has been modelled considering an adjustment of the stride length of pedestrians in bottlenecks (Von Sivers and Köster, 2015).

In the case of the PTI, Shen (2008) states that social behaviour can be studied in two distinct areas with different functions: circulation and waiting zones. In the circulation area, evacuation and dissipation behaviours take place, while the boarding and alighting behaviours are carried out in the waiting zones. However, in actual metro stations with PEDs there are no clear differences between these two areas (e.g. there is a lack of demarcations or signs) and therefore the platform is considered as one whole piece for circulation of passengers (Wu and Ma, 2013). In particular, Wu and Ma (2013) proposed a new division method for these waiting zones based on different rectangular shapes. The idea of dividing the waiting area for a more in-depth analysis has been employed by other researchers as well. For example, Shen (2001) states that the shape of the waiting zone can be represented as a parabola, while Lu and Dong (2010) suggested it be a fan or spectrum. Moreover, Seriani and Fernandez (2015b) reported that the use of a rectangular "keep-out zone" in front of a door on the platform reduced the interaction of passengers when they respected this area by queuing or clustering to the side of the doors rather than waiting in front of the door. However, all these authors have considered fixed values for those shapes, which do not necessarily represent the interaction of passengers, especially considering that the boarding and alighting movements change over time (e.g. before and after the train arrives).

Passengers in metro stations move in groups (only boarding, only alighting, and simultaneously) in which each passenger follows the passenger that is in front (Harris, 2006; De Ana Rodriguez et al., 2016). Their movement is freely in any space and is only limited by

the geometry of the walking environment (Still, 2000). Some researchers (Hoogendoorn and Daamen, 2005; Seyfried et al., 2009) have studied the passenger flow through bottlenecks in a corridor by performing laboratory experiments, and found that the capacity was only increased if a new lane was formed or when the "zipper effect" (passengers are overlapped forming two lanes) was presented. In addition, the behaviour in bottlenecks has been simulated by Guy et al (2010), in which pedestrians formed an "arch" reaching a higher density near the doors. This is shown in different laboratory experiments of boarding and alighting (Daamen et al., 2008; Fernandez et al., 2015; Seriani and Fernandez, 2015b). Similarly, some authors (Karekla and Tyler, 2012; Fujiyama et al., 2014) have studied by the means of laboratory experiments, the effect of layouts of the train-platform space on improvement of the flow rate, accessibility and the passenger service time.

Despite the wide variety of research conducted to aid understanding and optimization of platform design both for safety and service delivery, there have been few detailed studies 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 method to measure interaction, which we hope will help operators further optimize service both for when PEDs are present.

2. Hypothesis and objectives

PEDs can change the behaviour of passengers. But is this behaviour related to interaction? The main question of this research is how can be measured and classified interaction when PEDs are used in the platform-train interface (PTI)? The hypothesis is that interaction is higher near the doors and decrease as the distance from the train door increases. In addition, interaction is produced when the personal space is reduced or when the overlap (simultaneously boarding and alighting) is increased.

It is proposed as a general objective to determine, by means of laboratory experiments, a new method to measure the interaction of passengers in the boarding and alighting at metro stations. The specific objectives are: a) identify the typical patterns of movement at London Underground (LU) stations; b) to simulate different scenarios of boarding and alighting with PEDs and without PEDs at University College London's Pedestrian Accessibility Movement and Environmental Laboratory (PAMELA); c) to create a new indicator of interaction based on the types of queues, formation of lanes, density by layer, and distance between passengers; d) to propose some recommendations on how the interaction between passengers boarding and alighting can be reduced. As a case study it was used the London Underground, but the results can be expanded to other metro and LRT systems.

3. Method

According to Seriani and Fernandez (2015a) to select the main variables of study, any variable in a metro station should be classified into one of the three groups: physical (e.g. width of the platform), spatial (e.g. layout of the train), and operational (e.g. frequency of the train). In this work Green Park Station (GRP) and Westminster Station (WES) were chosen as case studies. The biggest differences between both stations were that WES uses platform edge doors (PEDs), while GRP does not use PEDs. Both stations were part of a complete CCTV video recording study solicited by London Underground Limited (LU) and provided the videos to the members of the Pedestrian Accessibility Movement Environmental Laboratory (PAMELA) in November 2014. In this study physical and spatial variables were fixed, while operational variables varied during the observation (see Table 1 and Table 2).

Table 1: Physical and spatial variables studied at GRP and WES stations

Variable	Type	Observation
Total platform width (mm)	Physical	3300 (included PEDs in WES)
Distance between yellow line and edge on platform (mm)		300 (included PEDs in WES)
Door width (mm)		1600 (2 double doors of 800mm)
Standback (mm)		200 between door and end seats 300 between door and centre seats
Horizontal gap (mm)		90
Vertical gap (mm)		170 (GRP); 0 (WES)

PEDs		No (GRP); Yes (WES)
Number of fixed seats		12 (4 in centre and 4 at each end)
Number of tip-up seats		8 (2 on each side of centre seating)

Table 2: Operational variables studied at GRP and WES stations

Variable	Type	Observation
Number Passenger Movements (pass)	Operational	Total number of boarders and alighters in segments of 5 s
Types of queues on the PCA		Passenger were clustered or queuing in front or at the side of the doors
Formation of lanes		Number of lanes formed for boarding and alighting at doors

The operational variables at GRP and WES were recorded during the most congested hour of the day (8:15 to 9:15 am and 5:15 to 6:15 pm), reaching a flow of 30 train/h and an average frequency of 2 minutes with a standard deviation of 1 min. To do this, 15 days (5th – 25th of November 2014) of data were collected using the software Observer XT 11 and the videos were converted into .avi format.

In relation to the scenarios, the exact train loadings were defined (i.e. number of people boarding, alighting or remaining on the train) as well as the different situations to be tested, which were based on the observation of the CCTV footage at GRP and WES. For this study it was used the loads described in Table 3. Three scenario of ratio (R) between boarding and alighting were defined (R=4, R=1, R=0.25). Each of these scenarios were tested with PEDs and without PEDs. The LC_0 and LC_1 loads were only tested to prepare 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.

Table 3: Loads used in the experiment

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

These scenarios were simulated in PAMELA using a mock-up of an underground tube carriage and a portion of the platform with similar characteristics of GRP (without PEDs) and WES (with PEDs). The mock-up was 10.00-m long and 2.65-m wide, with 20 seats (12 fixed seats and 8 tip-up seats), and two double doors of 1.6-m width. This produced a total floor area of 17.46 m^2, which allowed a capacity of 90 passengers (for a density of 4 pass/m^2) or 142 passengers (for a density of 7 pass/m^2) inside the train. The horizontal gap between the train and the platform was equal to 90 mm, while the vertical gap was 170 mm (with PEDs) and 0 mm (without PEDs). The platform was 10.00-m long and 3.30-m wide.

As there was limited space at PAMELA to simulate the behaviour of each passenger before the train arrived, the analysis was focused on the period between the train doors opening and closing (i.e. after the train arrived). For this simulation we recruited 110 participants to form 11 groups of 10 passengers each. In addition, boarding passengers used red hats and alighting passengers used white hats, and each set of 10 passengers wore different coloured bibs in which 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 (when all passengers were standing on the platform) and 5.15 pass/m^2 inside the car (when all passenger were inside the train). At the experiments passengers were

instructed to walk "naturally", as if they were boarding and alighting a train in the LU. To make sure that this behaviour was represented over time, randomly groups were chosen to board, alight or remain inside the carriage.

To obtain the position (x, y) of each passenger a tracking software was used. The use of automatic tracking can help to save time and is much easier for users to identify how passengers are moving, especially in spaces with high interaction (e.g. boarding and alighting). In this study Petrack was used, which is the latest software used to extract each passenger trajectory from video recordings (Boltes and Seyfried, 2013). The cameras were located at a height of 4 m from the floor in the PAMELA laboratory.

Considering the hypothesis of this research the interaction was measured in a new space defined as platform conflict area (PCA), which is represented as a semi-circular space with radius Li, in which high-density situations were reached (more than 2.17 pass/m² or LOS = F in Fruin, 1971). The radius Li of the PCA denotes the distance of influence of the train door i (see Figure 1 and Figure 2). To measure the interaction, the PCA was divided into six layers of 50 cm each, which represents the body depth of each passenger defined by Fruin (1971). The density by layer (number of passenger boarding and alighting divided by the area of each layer) and the distance between passengers (Euclidian distance between the coordinates (x,y) of the heads of two passengers) were obtained in the PCA. In this work the Level of Interaction (LOI) was defined as an indicator to measure the interaction between passengers boarding and alighting at metro stations. To create the LOI four operational variables were measured in the laboratory experiments: a) types of queues; b) formation of lanes; c) density by layer; and d) distance between passengers.
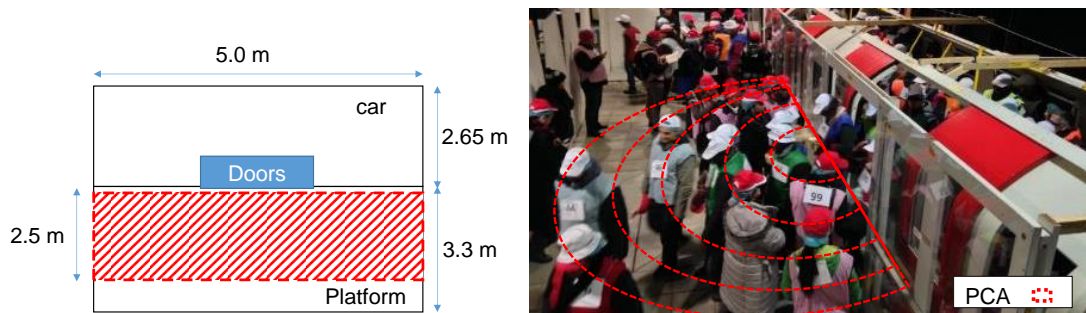

Figure 1: Rectangular area captured by the cameras (left) and PCA with PEDs (right) at PAMELA
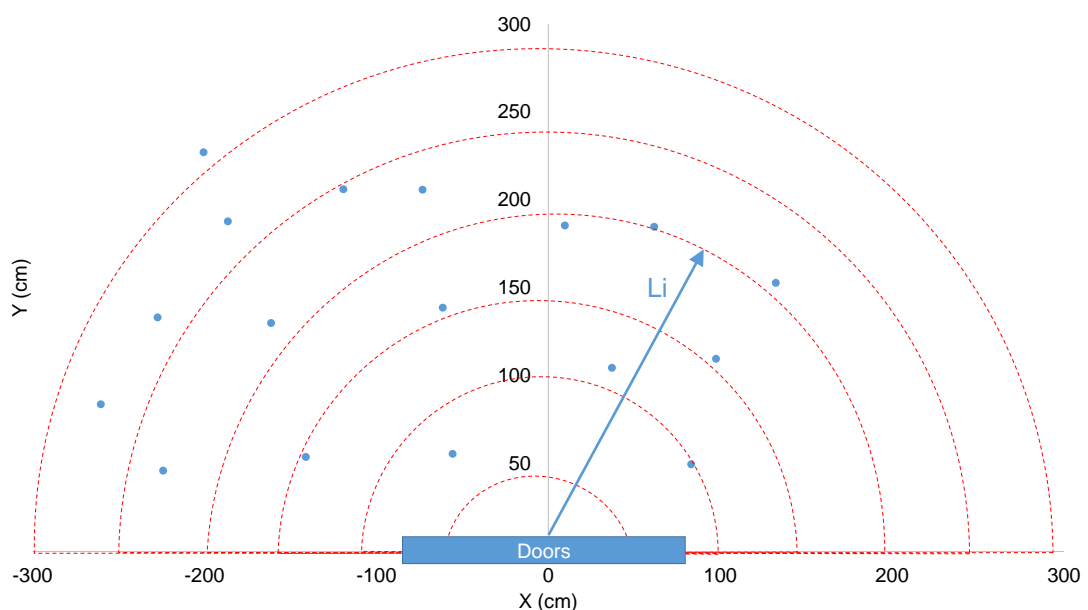

Figure 2: PCA in layers of 50 cm each to measure the position of passengers (circles)

4. Results

4.1 Passengers demographics

The subjects used in PAMELA were volunteers, 46% men and 54% women, 78% of them were regular users of the London Underground and mostly were under 45 years old (15% were under 24 years, 26% 25-34, 19% 35-44, 27% 45-59, 7% 60-64, and 7% more than 65 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.

4.2 Types of queues and formation of lanes

As a result of the observation at GRP and WES, the typical pattern of behaviour between boarding and alighting was identified (see Figure 3). When the train doors commenced opening passengers started to form queues, reaching a higher density near the doors (similar to the "arch" effect in bottlenecks simulated by Guy et al., 2010). These queues were classified into four types: waiting in front of doors, clustered to the side of the doors, queuing in front of the doors, and queuing at the side of the doors. In the case of WES the use of PEDs helped passengers know where doors were going to be on the platform and reduced the interaction between passengers by queuing at the side of the doors rather than in front. In addition, the Platform Train Interface (PTI) was defined as the space between the train doors and PEDs in the case of WES, whilst at GRP it was the space between the train doors and the yellow line on the platform. Passengers without PEDs entered earlier the PTI than with PEDs. These behaviour related to the PTI and types of queues were also identified at the PAMELA experiments. When the ratio between boarding and alighting (R) was equal to 4, then passengers were mostly waiting in front of the doors, while when R was equal to 0.25, passengers were clustered or queueing at the side of the doors before boarding. In the case where R = 1 passengers were waiting (or clustered) to the side and in front of the doors before boarding. The formation of queues was caused because boarding passengers could see the number of alighting passengers inside the train. More explanation on this can be founded in De Ana Rodriguez et al., (2016).

1. Train Arrival; 1st passenger enter PTI

2. Train door commences opening; formation of queues

3. Alighting first (1 lane); board wait at the side of doors

4. Alight completed; 3 lanes formed for boarding

5. End boarding; last passenger exit PTI
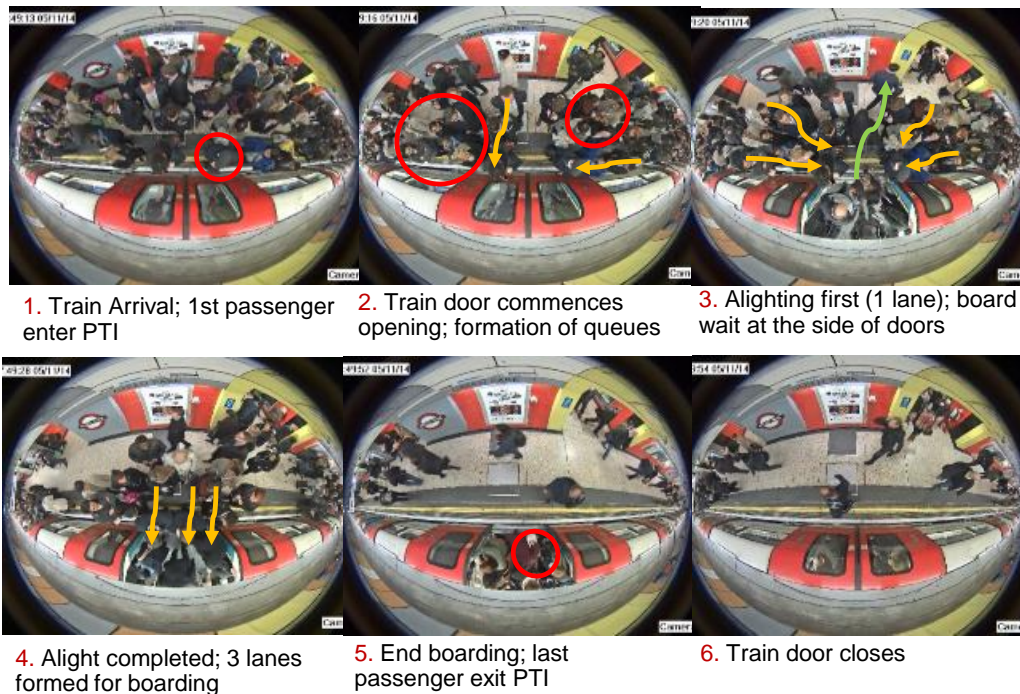
6. Train door closes

Figure 3: Example of movement pattern at GRP

In relation to formation of lanes Figure 3 shows that boarding passengers were influenced by alighting passengers as an unequal priority was observed when alighting had preference than boarding. This mean that that interaction is related to the time that boarding and alighting was simultaneously (overlap). For example, when the ratio between boarding and alighting (R) was

equal to 0.25 passengers wait until the alighting process was almost finished to board the train, reaching a lower overlap and therefore less interaction between passengers boarding and alighting. When R = 1 passengers wait until segment 10th-15th second to start boarding the train, reaching a medium interaction. In the case of R = 4 passengers started boarding the train from the segment 5th-10th second, because there were four time more boarding passengers than alighting. This situation (R = 4) produced more opportunities to board the train before the end of alighting, reaching a higher overlap and therefore more interaction between passengers boarding and alighting. In addition, when the value of R increased alighting formed only one lane due to collision avoidance with passenger boarding. This situation produced the phenomena of formation of lanes at the doors, which were different to a supermarket's queue in which people are served in FIFO ("First in First out"). The formation of lanes were also seen in the PAMELA experiments. Figure 4 shows that when R = 4, then one alighting lane was formed, while two lanes for alighting were formed when R = 0.25. In both cases two lanes for boarding were formed at the side of the doors and an average bidirectional flow of 1.0 pass/s was reached in the doors. In the case when R = 1, between one and two lanes were formed for alighting reaching an average bidirectional flow of 0.80 pass/s in the doors.

As a result of the LU observation (GRP and WES) and laboratory experiments (PAMELA), the Level of Interaction (LOI) was defined as an indicator to measure the interaction between passengers boarding and alighting based on the types of queues and formation of lanes. The LOI was classified into three levels: low, medium, and high. (See Table 4).
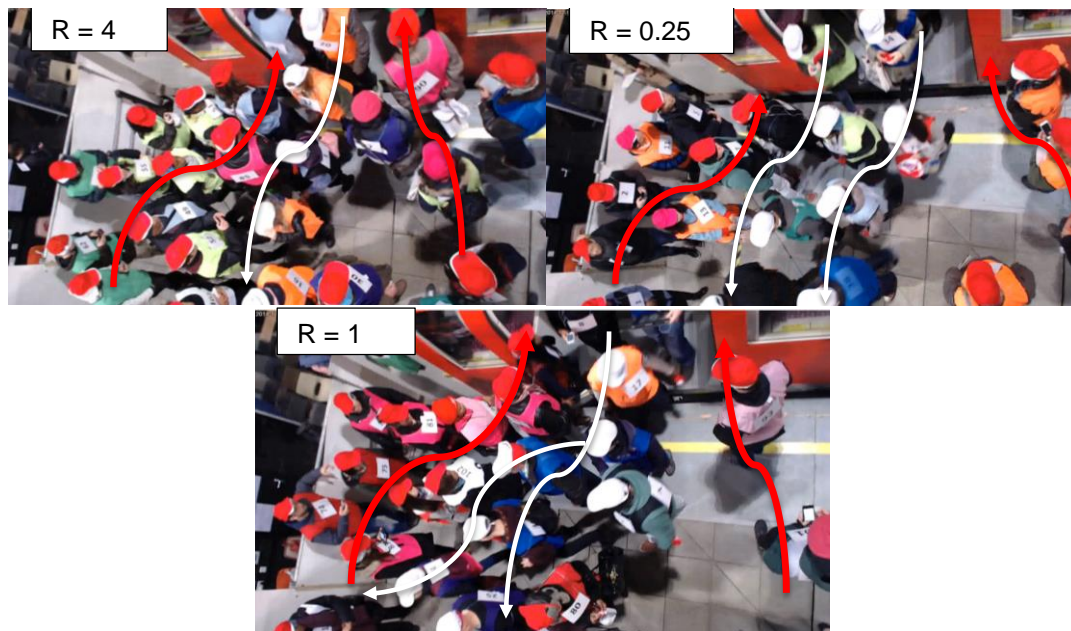

Figure 4: Formation of lanes when R was changed at PAMELA

Table 4: Proposed classification of LOI with respect to queues and lanes

LOI	R (boarding/ alighting)	Type of queue for boarding passengers	Formation of lanes for alighting passengers
High	4	Passengers wait in front of door	1 lane
Medium	1	Clustered at the side and in front of door	Between 1 and 2 lanes
Low	0.25	Clustered or queuing at the side of door	2 lanes

4.3 Density by layer

Figure 5 shows the average maximum density by layer on the PCA just before the doors started to open (segment of time 0th seconds). When R = 4 a high density 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 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. These results supported the behaviour of passengers with respect to the types of queues and formation of lanes (see Section 4.2), in which a high Level of Interaction (LOI) was reached when R = 4 and a low LOI was reached when R = 0.25.
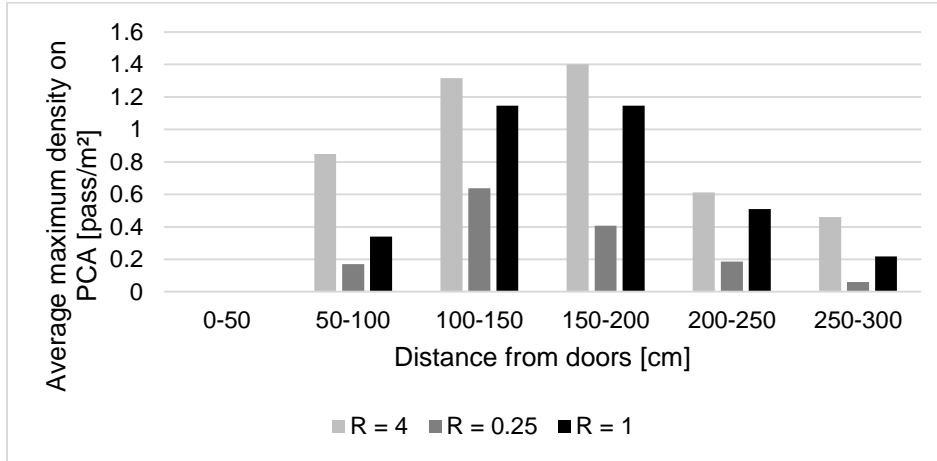

Figure 5: Average maximum density by layer on the PCA just before PEDs started to open at PAMELA

Figure 6 shows the maximum density by layer on the PCA after the doors started to open. For all values of R (ratio between boarding and alighting) the average maximum density on the PCA followed a logarithmic distribution with a coefficient of correlation between 0.97 and 0.99. This mean that the density reached a higher value in the first layer (up to 6.88 pass/m^2 when R = 4) and decreased as the distance from the door increased. Considering that the personal space is the inverse of the density, then layers on PCA with a high density of passengers presented a lower personal space, and therefore a high interaction. This situation validated the hypothesis of this research, in which interaction was considered higher near the doors and decreased as the distance from the door increased.

As a result of the laboratory experiments (PAMELA) the LOI was defined as an indicator to measure the interaction of boarding and alighting (after the doors started to open) as a function of the density by layer. The LOI was classified into three levels (see Figure 6). When the LOI was "high" the density reached over 4.0 passengers per square metre, which is the density used by LUL (2012) to obtain capacity in static modelling. In the case of a "low" LOI the density reached a value lower than 2.17 pass/m^2, which is the value defined by HCM (2000) for crowded situations. The LOI was compared to the LOS of Fruin (1971) in which the PCA was considered a rectangular area of 15 m^2 (3.0 m-wide and 5.0 m-long) instead of a semi-circular space. This rectangular area reached a maximum overall density of 1.98 pass/m^2 equivalent to a "low" LOI, obtaining up to 3.5 times less density than the method by layers (see Table 5). Therefore, the LOI was more representative of the interaction between passengers boarding and alighting than the LOS with respect to density.

Table 5: Maximum overall density (pass/m^2) on rectangular PCA at PAMELA

Scenario	Overall density		Indicator	
	PEDs	No-PEDs	LOS (Fruin, 1971)	LOI
R = 4	1.82	1.98	LOS E	Low
R = 1	1.30	1.38	LOS E	Low
R = 0.25	0.99	1.06	LOS D	Low

To identify if the use of PEDs influenced the density of passengers by layer, a Mann-Whitney U test was used with a significance level of 5% (α = 0.05) to compare each group (PEDs and No-PEDs) for each layer and value of R. The null hypothesis (H$_0$) was defined as the two medians being equal or when there was no difference in the sum of the two groups. The results

of the Mann-Whitney U test showed that all cases presented a U-value higher than the U-Critical = 23 (group size of $n_1 = n_2 = 10$) obtained from the statistical analysis (see Table 6). This mean that the null hypothesis is accepted, i.e. the use of PEDs had no statistical difference in relation to the density by layer compared to the case without PEDs.
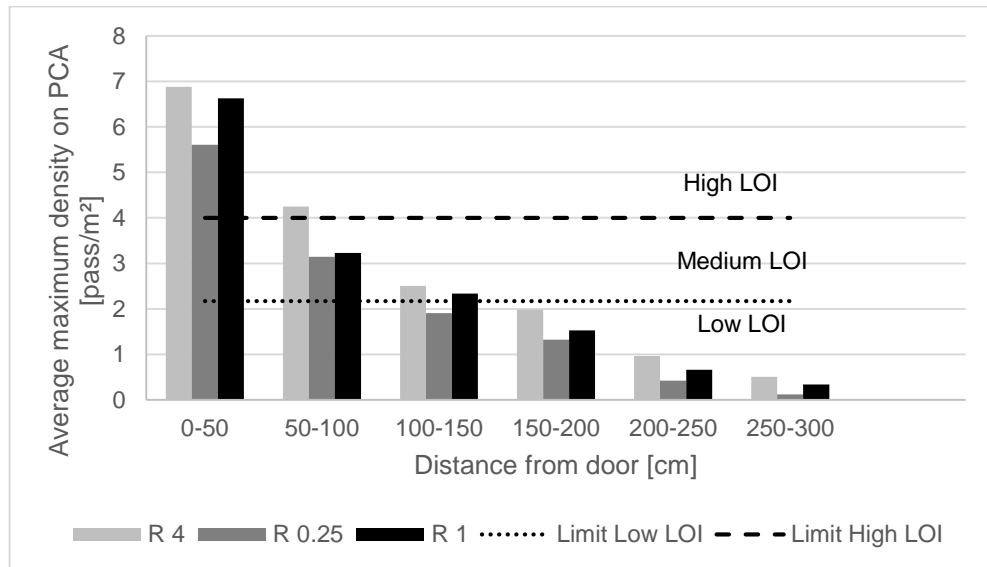

Figure 6: Average maximum density by layer on semi-circular PCA with PEDs at PAMELA

Table 6: Average maximum density (pass/m^2) by layer in each scenario at PAMELA

Scenario	R = 4			R = 1			R = 0.25		
Layer (cm)	PEDs	No-PEDs	U-value	PEDs	No-PEDs	U-value	PEDs	No-PEDs	U-value
0-50	6.88	6.62	45.50	6.62	6.11	39.00	5.61	5.86	46.50
50-100	4.25	4.33	49.00	3.23	3.31	47.00	3.14	3.40	42.00
100-150	2.51	2.68	35.00	2.34	2.17	39.50	1.91	1.95	46.50
150-200	1.99	1.99	49.00	1.53	1.50	46.50	1.32	1.25	42.00
200-250	0.97	1.14	27.50	0.66	0.76	35.50	0.42	0.49	37.00
250-300	0.51	0.49	48.50	0.34	0.38	39.00	0.12	0.19	29.00

4.4 Distance between passengers

Figure 7 shows that when the ratio between boarding and alighting (R) was equal to 0.25, there was more space for passengers to alight, and therefore the average distance between passengers alighting was slightly larger compared to the case when R = 1 or R = 4. This behaviour occurred in the case with PEDs and without PEDs. In addition, Figure 8 shows the average distance between heads of passengers boarding in segments of 5 seconds in the experiments with PEDs. In the case of R = 0.25 just before the doors started to open (segment time 0th seconds) the distance between heads reached almost the double compared to R = 4 or R = 1 due to the available space on the platform (R = 0.25 had four times less boarding passengers than with R = 4). These results supported the behaviour of passengers with respect to the types of queues and formation of lanes (see Section 4.2).

As a results of these experiments the Level of Interaction (LOI) was created to measure the interaction between passengers as a function of the distance between them. The LOI was "high" when the distance between passengers was lower than 80 cm, which is the distance that passengers felt intimate as reported in the introduction of this paper. Therefore, according to the new indicator both situations (PEDS and No-PEDs) presented a "high" LOI after the doors started to open, reaching an average distance between heads of passengers lower than 80 cm in all the scenarios of R.

Similar to the density by layer (see Section 4.3) a Mann-Whitney U Test for a pairwise comparison between scenarios of R was done. As it is shown in Table 7 the U-value was

always higher than the U-Critical = 23 (group size of $n_1 = n_2 = 10$). Therefore, the null hypothesis (Ho) is accepted, i.e. the use of PEDs had no statistical difference in relation to the distance between heads of passengers compared to the case without PEDs.
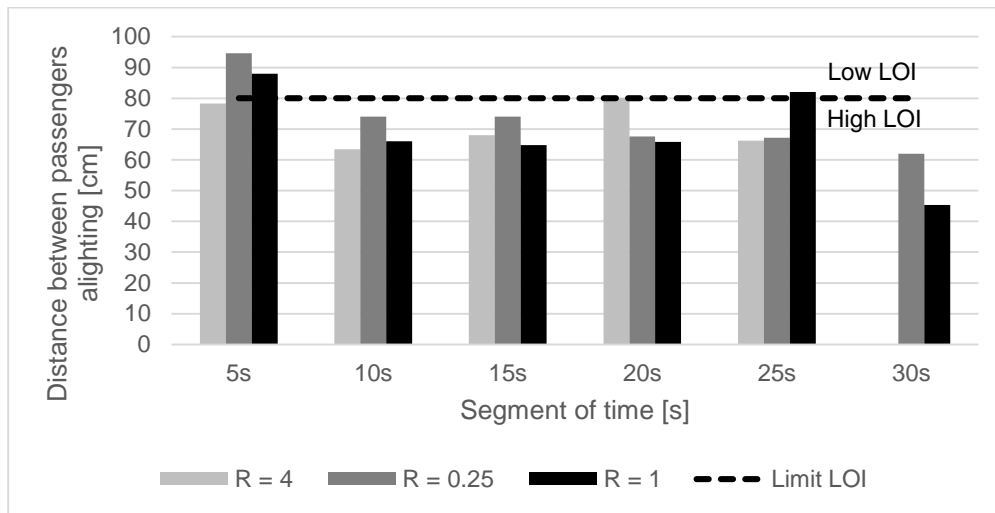

Figure 7: Average distance between passengers alighting with PEDs at PAMELA
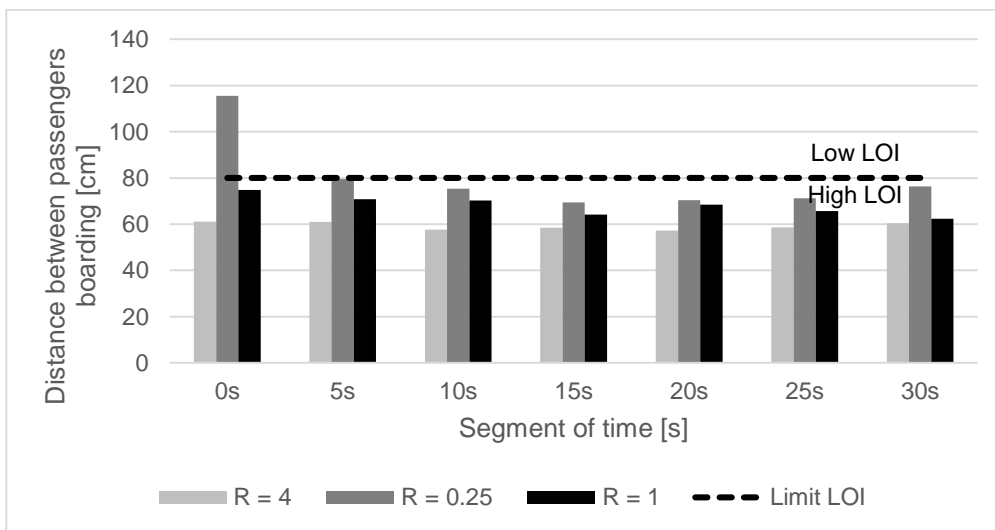

Figure 8: Average distance between passengers boarding with PEDs at PAMELA

Table 7: Average distance (cm) between heads of passengers at PAMELA

Scenario	Between passengers alighting			Between passengers boarding		
	PEDs	No-PEDs	U-value	PEDs	No-PEDs	U-value
R = 4	68.41	74.82	33	59.32	60.27	35
R = 1	67.94	70.76	45	68.08	76.67	41
R = 0.25	69.85	75.48	35	81.21	71.66	31

5. Recommendations to reduce interaction

To reduce the Level of Interaction (LOI) and avoid densities higher than 2.17 passengers per m^2 in the boarding and alighting process on the platform conflict area (PCA), some Pedestrian Traffic Management (PTM) measures can be implemented such as demarcations or signs on the platform. PTM is defined as is defined as "rational administration of movement of people to generate adequate behaviour in public spaces to improve the use of pedestrian infrastructure" (Seriani and Fernandez, 2015b, 76).

The LU observation and experiments results in Section 4 suggest that two lines on the platform can be marked to show the direction of passengers alighting, and two circles for passengers

boarding can be painted as waiting areas (see Scenario 1 in Figure 9). This PTM measure will avoid boarding passengers to wait in front of the doors, being an obstacle for alighting passengers and interrupting the formation of lanes. The minimum width of each line w_a should be 0.6 m which represents the shoulder breadth of each passenger as reported in Fruin (1971). Therefore, the maximum length of the line on the platform L_a should be no more than 2.4 m (starting from the doors) to allow a circulation space of at least 0.6 m-wide from the edge of the platform. In the case of the waiting area the radius r_b can be obtained depending on the number of passengers boarding for a density of 2.17 pass/m^2 defined as the limit of low LOI in this paper. For example, in the case of R = 4 in which the number of passengers boarding is equal to 40, if they distributed evenly in each waiting area, then r_b = 1.70 m. Another PTM measure can be suggested from the results in Section 4, in which a semi-circular space of radius r_a = 150 cm can be marked as a "keep out zone" on the platform and 2 lines for queuing at each side of the doors can be signed as a way to maintain clearance and avoid boarding passengers to enter this zone until alighting is finished (see Scenario 2 in Figure 9). The value of r_a was obtained considering the first three layers on the PCA in which the average maximum density reached more than 2.17 pass/m^2. The length and width of the queue lines for boarding in Scenario 2 are equal to the length and width of the lines for alighting in Scenario 1. These recommendations can be combined with other PTM measures (as reported in Fujiyama et al., 2008; Wu and Ma, 2012)) and tested as future research by the use of sensors and instruments at PAMELA.
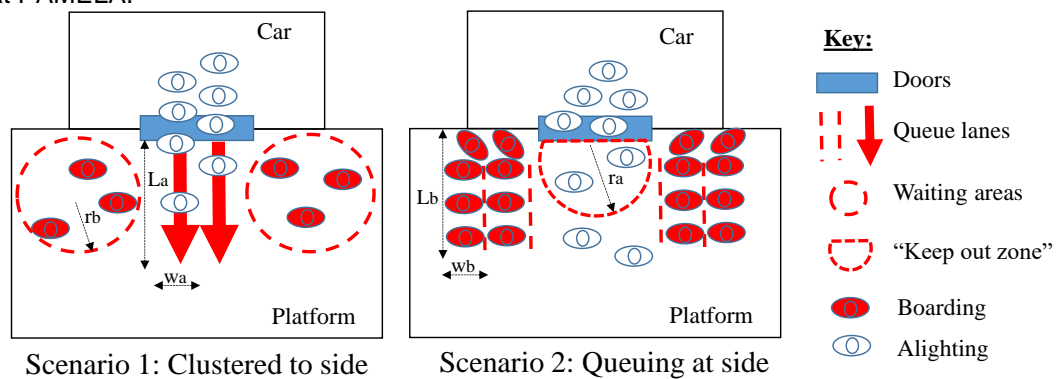

Scenario 1: Clustered to side   Scenario 2: Queuing at side

Figure 9: Recommendation of PTM on the PCA to reduce interaction

6.   Conclusions

This study presented a new method to measure the Level of Interaction (LOI) of passengers who were boarding and alighting a train and which included a new space defined as platform conflict area (PCA). The PCA consisted of a semi-circular shape of radius Li and a density measured by layers as interaction were higher near the doors and decreased as the distance from the door increased. To validate this hypothesis, 15 days of observation were recorded at two London Underground stations and 4 days of simulation experiments were done at the University College London's Pedestrian Accessibility Movement Environmental Laboratory (PAMELA) to control exactly the number of passengers boarding and alighting. This method would help traffic engineers and policy makers to measure the interaction and use the LOI as a more precise indicator for the design of spaces in metro systems. This new indicator was based on four variables: a) types of queues; b) number of lanes; c) density by layer; d) distance between passengers. The LOI was classified into: low, medium, and high.

The observation results for GRP and WES showed an important relationship between the ratio of boarding and alighting (R) and the interaction between passengers. When R was equal to 4 passengers started boarding the train earlier (i.e. before all the passengers had fully alighted) than when R was equal to 1 or 0.25, reaching a higher interaction. When R=0.25 passengers wait until alighting was almost finished to board the train, reaching a lower interaction. The use of PEDs changed the behaviour of passengers. In WES, passengers knew where the train was going to stop on the platform and therefore a reduction in the interaction was reached due to passengers mostly queuing at the side of the doors rather than in the front just before boarding. This benefit was obtained especially when R was equal to 1.

With respect to the experiments, the use of PEDs also helped to reduce the interaction of passengers before boarding the car as they were mostly queuing at the side of the doors rather than in the front. In addition, the density by layer was obtained on the PCA, which followed a logarithmic distribution in all the scenarios with a coefficient of correlation between 0.97 and 0.99. The LOI reached a "high" level for the first layer (density > 4.0 pass/m^2) and a "low" level in the last three layers (density < 2.17 pass/m^2). These results supported the hypothesis done in this work, in which the interaction between passengers was higher near the doors and decreased as the distance from the door increased. In addition, the density by layer was more representative of the interaction than the overall density, which reached only a maximum value of 1.98 pass/m^2 (3.5 times less than the density by layer). The last variable studied at PAMELA was the distance between the heads of passengers, in which for all cases of R the LOI reached a "high" level (distance between passengers lower than 80 cm). In addition, based on a Mann-Whitney U test there was no statistical differences between PEDs and No-PEDs.

Some limitations of this study are related to the use of the tracking tool. Unfortunately because of the varying frame rate and large steps in-between the videos it was not possible to extract any trajectories automatically. This situation was not possible to solve because the videos were highly compressed. This situation was not possible to solve because the videos were highly compressed. In future, these errors can be rectified before the beginning of the study. In addition, further research needs to be conducted to test other pedestrian traffic management measures by the use of sensors and instruments at PAMELA facility.

References
Boltes, M., Seyfried, A. (2013). Collecting Pedestrian Trajectories. In: Neurocomputing, Special Issue on Behaviours in Video, 100, 127-133.

Carreno, M., Willis, A., Stradling, S. (2002). Quality of service for pedestrians: closing the gaps in knowledge. In Proceedings International Conference on Traffic and Transportation Studies (ICTTS) 2002, 326-333, Guilin.

Clarke, R. V., and Poyner, B. (1994). Preventing suicide on the London Underground. Social science & medicine, 38(3), 443-446.

Daamen, W., Lee, Y. and Wiggenraad, P. (2008). Boarding and alighting experiments: an overview of the set up and performance and some preliminary results on the gap effects. Transportation Research Record 2042, 71-81.

De Ana Rodriguez, G., Seriani, S., Holloway, C. (2016). The impact of platform edge doors on passengers boarding and alighting time and platform behaviour. Transportation Research Record. (Sent for publication on 1st August 2015).

Evans, G. W., Wener, R. E. (2007). Crowding and personal space invasion on the train: Please don't make me sit in the middle. Journal of Environmental Psychology, 27(1), 90-94.

Fernandez, R., Valencia, A, Seriani, S. (2015). On passenger saturation flow in public transport doors. Transportation Research Part A, 78, 102-112.

Fruin, J.J. (1971). Designing for pedestrians: a level-of-service concept. Highway Research Record 377, 1-15.

Fujiyama, T., Nowers, J., Tyler, N., (2008). Investigation into train dwell time. Submitted to the Department for Transport, UK (unpublished).

Fujiyama, T., Thoreau, R., and Tyler, N. (2012). The effects of the design factors of the train-platform interface on pedestrian flow rates. Pedestrian and Evacuation Dynamics, Springer International Publishing, 2014, 1163-1173.

Gérin-Lajoie, M., Richards, C. L., Fung, J., McFadyen, B. J. (2008). Characteristics of personal space during obstacle circumvention in physical and virtual environments. Gait & posture, 27(2), 239-247.

Guy, S. J., Chhugani, J., Curtis, S., Dubey, P., Lin, M., and Manocha, D. 2010. "Pledestrians: a least-effort approach to crowd simulation." In Proceedings of the 2010 ACM SIGGRAPH/Eurographics symposium on computer animation 119-128. Eurographics Association.

Hall, E. (1966). The hidden dimension. Doubleday, Garden City, 14, 103-124.

Harris, N. G. (2006). Train boarding and alighting rates at high passenger loads. Journal of advanced transportation, 40(3), 249-263.

Hartnett, J.J., Bailey, K.G., Hartley, C.S. (1974). Body height, position, and sex as determinants of personal space. Journal of Psychology, 87, 129–136.

Highway Capacity Manual. (2000). TRB Special Report 209, National Research Council, Transportation Research Board, Washington, DC.

Hoogendoorn, S. P. and Daamen, W. (2005). Pedestrian behavior at bottlenecks. Transportation Science 39(2), 147-159.

Karekla, X., Tyler, N. (2012). Reduced dwell times resulting from train–platform improvements: the costs and benefits of improving passenger accessibility to metro trains. Transportation Planning and Technology, 35(5), 525-543.

Kyriakidis, M., Hirsch, R., and Majumdar, A. (2012). Metro railway safety: An analysis of accident precursors. Safety science, 50(7), 1535-1548.

Little, K. B. (1965). Personal space. Journal of Experimental Social Psychology, 1(3), 237-247. Lu, J. and Dong, F. (2010). Statistical analysis of the passenger distribution before getting on subway train. Urban Mass Transit, 13(7), 53-56 (in Chinese).

LUL (2012). Station Planning Standards and Guidelines. London Underground Limited, London.

NFPA-130 (2007). Standard for Fixed Guideway Transit and Passenger Rail Systems. Chapter 5, Stations. National Fire Protection Association. Massachusetts.

Pushkarev, B., Zupan, J. (1975). Urban space for pedestrians. The MIT Press, Cambridge, Massachusetts.

Qu, L., and Chow, W. K. (2012). Platform screen doors on emergency evacuation in underground railway stations. Tunnelling and Underground Space Technology, 30, 1-9.

RSSB (2008). Management of on-train crowding Final Report. Rail Safety and Standards Board. London.

Sanders, J.L. (1976). Relationship of personal space to body image boundary definiteness. Journal of Research in Personality, 10, 478–481.

Seriani, S., and Fernandez, R. (2015a). Planning guidelines for metro-bus interchanges by means of a pedestrian microsimulation model in Chile. Transportation Planning & Technology, 38(5), 569-583.

Seriani, S., Fernandez, R. (2015b). Pedestrian traffic management of boarding and alighting in metro stations. Transportation Research Part C, 53, 76-92.

Seyfried, A., Rupprecht, T., Passon, O., Steffen, B., Klingsch, W., and Boltes, M. (2009). New insights into pedestrian flow through bottlenecks. Transportation Science, 43, 395-406.

Shen, J. (2001). The research for dynamic distribution of passenger and the width of platform. Urban Rapid Transit, 4(1), 21-25 (in Chinese).

Shen, J. (2008). Simplified calculation for the width of on and off regions of station platform. Urban Rapid Transit, 21(5), 9-12 (in Chinese).

Sommer, R. (1969). Personal Space: The Behavioral Bases of Design. Prentice Hall, NJ
Still, K. (2000). Crowd Dynamics. PhD Thesis University of Warwick, UK.

Teknomo, K. (2006). Application of microscopic pedestrian simulation model. Transportation Research Part F, 9(1), 15-27.

Von Sivers, I., and Köster, G. (2015). Dynamic stride length adaptation according to utility and personal space. Transportation Research Part B: Methodological, 74, 104-117.

Webb, J.D., Weber, M.J. (2003). Influence of sensor abilities on the interpersonal distance of the elderly. Environment and Behavior, 35(5), 695–711.

Wu, J., & Ma, S. (2013). Division method for waiting areas on island platforms at metro stations. Journal of transportation engineering, 139(4), 339-349.