sustainability

MDPI

Article

Analyzing the Effect of Crowds on Passenger Behavior Inside Urban Trains through Laboratory Experiments—A Pilot Study

Sebastian Seriani [1,*], Jose Miguel Barriga [2], Alvaro Peña [1], Alejandra Valencia [1], Vicente Aprigliano [1], Lorena Jorquera [1], Hernan Pinto [1], Matías Valenzuela [1] and Taku Fujiyama [3]

1 Escuela de Ingeniería de Construcción y Transporte, Pontifica Universidad Católica de Valparaíso, Valparaíso 2362804, Chile
2 Facultad de Ingeniería y Ciencias Aplicadas, Universidad de los Andes, Santiago de Chile 7620001, Chile
3 Faculty of Civil, Environmental and Geomatic Engineering, University College London, Chadwick Building, Gower St., London WC1E 6BT, UK
* Correspondence: sebastian.seriani@pucv.cl

Abstract: The objective is to study the distribution of passengers inside urban trains for different levels of crowding. The study is carried out through the observation of videos made by laboratory experiments in which a mock-up of a carriage represented the boarding and alighting process. The Fruin's Level of Service (LOS) was adopted, but with a different approach, in which the train is divided into five zones (central hall, central aisle, side aisle, central seats and side seats). The experiments are based on the behavior of passengers in the London Underground; however, this study could be expanded to any conventional rail or LRT system. For the laboratory experiments, it is proposed to build a metro carriage and a corresponding platform section, and the scenarios will include different levels of crowding of passengers boarding and alighting to produce a variation in the density on the platform. According to the crowding level, the results allow obtaining the distribution and movements generated by passengers in the five zones for different instants of time during the process of boarding and alighting. It is observed that passengers are distributed according to safety and efficiency conditions. For example, passengers tried to avoid contact with each other unless it is inevitable. In relation to comfort, the seats of the carriage are always used even if there is a low level of crowding. If the crowding level increases, the boarding and alighting time go up. In addition, passengers will spend one or two seconds more if the "let's get off before getting on the carriage" behavior is breached. This kind of experiment can be used in further research as a way to test "what-if" scenarios using this new method of discretization of the space inside the train, which cannot be tested in existing stations due to restrictions such as the weather, variability of the train frequency, current design of the trains, among others. New experiments are necessary for future research to include other types of passengers such as people with disabilities or reduced mobility.

Keywords: passenger; train; distribution; crowding; boarding and alighting time; behavior

check for updates

Citation: Seriani, S.; Barriga, J.M.; Peña, A.; Valencia, A.; Aprigliano, V.; Jorquera, L.; Pinto, H.; Valenzuela, M.; Fujiyama, T. Analyzing the Effect of Crowds on Passenger Behavior Inside Urban Trains through Laboratory Experiments—A Pilot Study. *Sustainability* **2022**, *14*, 14882. https://doi.org/10.3390/su142214882

Academic Editors: Jingxu Chen, Jie Ma and Xinlian Yu

Received: 29 September 2022
Accepted: 5 November 2022
Published: 10 November 2022

1. Introduction

The population in the city of London is around nine million inhabitants and grows every year to the order of 40,000. Population growth within the region has led to extra efforts being made to maintain the quality of life of the people who live in the center of the city and its outskirts. To maintain the residents' quality of life in the capital, it is very important to talk about the distribution of people in the city and its outskirts, due to the large population. Among the fundamental reasons it is important to consider, a wide distribution is the government's effort to create efficient systems in health, education, infrastructure, and transportation [1].

Like many cities in the world, one of the ways to maintain and improve people's quality of life is related to the development of sustainable mobility plans; this must consider public transport such as railways, which need to improve capacity and punctuality [2]. Due to the requirements in the city of London, many economic resources are invested every year to improve public transport [3]. In a non-pandemic situation, the London Underground transports 2.9 million people daily [4], equivalent to 11% of the modal split. It is the public transport that moves the largest number of people in London due to its efficiency in terms of speed, quality and decongestion of the streets. In 2020, approximately 1.0 million passengers used the subway as a means of transportation, which means a decrease of 66% compared to 2019, mainly due to the low demand then as a result of the health emergency caused by COVID-19 [4]. This decrease leaves the London Underground as the least used public transport system, with only 5% of the modal split, compared to 6% for the Overground train system and 11% for buses.

It is expected that in a post-pandemic period the situation will be “normalized”, reaching values like those reported in 2019. This would imply, as in other cities such as Buenos Aires [5], that situations of non-compliance with regulations are reached due to crowding levels in the train–platform interface. This space is the most complex to analyze, which has registered a high interaction between passengers getting on and off the trains [6,7]. If the interaction increases the train will maintain at the station for a longer time, due to the time each passenger gets on and off the train [8]. By the above, it is important to add that there is a poor distribution of passengers inside the train, which is due in part to the disorderly flow in the process of getting on and off together with the lack of signaling or poor positioning of the passengers, seats, and support handles. Similarly, most people tend to gather in the central hall area due to the location of the vertical handrail, which further exacerbates the problem [9,10]. Therefore, it is inevitable that accidents, harassment, and assaults, among other problems, occur due to the reduction in the available space that is generated [11]. At the same time, it should be considered that the mobility of some people is reduced due to their age, physical problems, or items they carry (wheelchairs, canes, etc.), which adds to the problem of space that is presented in this transport mode [12].

Due to the aforementioned reasons, the problems generated by the different crowds of people and their behavior inside the wagons must be addressed. Likewise, it is necessary to determine how these conditions affect the boarding and alighting times at the train–platform interface, and their impact on the distribution of passengers which is the main objective of this study. For this, the specific objectives are the following: (a) identify the variables that affect the distribution of passengers inside an urban train; (b) define a method to study the distribution of passengers; (c) analyze different levels of crowding by the means of experiments carried out in the Pedestrian Accessibility Movement Environment Laboratory (PAMELA) of University College London (UCL); and (d) propose design and operation recommendations for the interior of trains based on the analysis carried out.

The structure of the paper is divided into five sections: In Section 2 different studies of passenger behavior at the platform–train interface are reported. Next, in Section 3 the experimental method is defined. In Section 4 the results are analyzed, followed by the conclusions in Section 5.

2. Passengers’ Behavior on Public Transport

The distribution of passengers on public transport is determined by different factors which depend mainly on the moment in which the trip is made due to the behavior of passengers. According to RSSB [13], four factors can affect the behavior of passengers on public transport: the density of the train or platform (e.g., personal space), the physical design of the train (e.g., width of the platform, number of seats, or distribution of handrails), the information provided to passengers (e.g., maps, signage or screens), and the environment (e.g., weather). On the other hand, Webb and Weber [14] have mentioned that the behavior assumed by passengers in situations of high interaction, such as urban trains, would also be determined by the ability to see, hear and move, and people’s ages and genders. In the same way, Hoogendoorn and Daamen [15] proposed that the behavior of passengers is determined by other characteristics such as the purpose of the journey, the familiarity of the route and the luggage carried. Moreover, Cox et al. [16] reported the difference between density and crowding, in which the behavior is affected by the stress of passengers in public transport environments. For Still [17] the behavior of passengers is related to the perception of risk and safety, in which crowd management measures are needed.

Another line of thought is reported by Schmidt and Keating [18], in which the behavior of passengers, and therefore their distribution inside an urban train, is determined by psychological elements organized in the states. The first state is defined as a behavioral state, where the passenger facing a crowd has no control or freedom of movement. The second state is defined as the cognitive state, which depends on the information given to the passenger before he/she faces a situation that compromises the capacity of the urban train. The last state is decisional, in which the passenger has full freedom to carry out the desired movement. In this sense, psychology plays a fundamental role when generating models that allow describing the distribution of passengers in crowded situations [19]. These studies are based on virtual ring models that are generated to mark each passenger's personal space depending on the type of relationship that exists. For example, if an unknown passenger approaches another passenger inside the train at a distance of less than 0.45 m, this passenger will feel that his/her personal space has been invaded [20,21].

From a physical perspective, Lam et al. [22] reported that the crowding situation in public transport environments can be related to the Level of Service of Fruin [23], in which the space used by each passenger is equivalent to 0.3 m^2 which considers 60 cm shoulder width and 50 cm body depth. In turn, when the passenger is in motion, this space increases to 0.75 m^2, which implies the movement of arms and legs [24]. If the density inside the train increases, each passenger becomes an obstacle, and therefore the space used by each passenger is experimentally represented as an ellipse with an area of 0.96 m wide and 2.11 m deep [25]. However, in a situation of crowding, it is also very important to consider other factors when talking about the space used by passengers such as age, sex and health; this is reported by Daamen and Hoogendoorn [26] through real-scale experiments.

When the trip is made during peak hours, more than 80% of the train capacity is used; the density occupied by passengers is 6 passengers/m^2, which is a very high density for a space as small as an urban train. As a consequence, the density directly affects the efficiency and safety of the train–platform interface. In terms of efficiency, the boarding time increases linearly with the passenger density while the alighting time per passenger grows exponentially and triples when the density of passengers on board reaches 6 passengers/m^2. This is explained by Tirachini et al. [27], in which the complexity of getting off a vehicle considers a high level of crowding. For example, an uneven distribution of passengers can increase the boarding and alighting time at the platform–train interface in metro stations [28]. Regarding safety, this interface between the train and the platform or platform–train interface (PTI) is the most complex space when it comes to boarding and alighting passengers. The PTI is the area in which the greatest number of interactions is reached, and therefore in which accidents mainly occur. For example, in the case of the United Kingdom, each year there are three million interactions on the national network (Railway Network); in these, 21% of safety risks (injuries and deaths) along with 48% of fatality risks occur at the train–platform interface [6].

To study the distribution of passengers against high crowds, different authors [29–36] have been performing real-scale experiments in which management measures are proposed to reduce the boarding and alighting time such as wider doors or the implementation of platform edge doors. For example, traffic management measures, such as waiting areas or the use of vertical handrails to channelize the flow inside the train, could reduce accidents and generate a more efficient and accessible platform–train interface by reducing the dwell time [37]. The dwell time considers a fixed component which is affected by the opening of doors, closing of these doors, and the time related to the mechanical movements of the train. In turn, the dwell time has a dynamic component that refers to the movements of passengers getting on and off, affecting the space occupied by passengers in the train–platform interface. Recently, real-scale experiments [38,39] have been carried out to represent the space occupied in the train–platform interface, in which a person with reduced mobility (for example, a wheelchair) occupies more space than a person without reduced mobility. In addition, the high density of passengers can affect not only the space occupied by each passenger but also the distribution of passengers on the platform [7]. The authors proposed a model of virtual rings to determine the location of passengers waiting to board the train, where a higher density generates difficulty for passengers who want to get off the train to the platform, affecting the boarding and alighting times. It should be considered that the study carried out by Seriani and Fujiyama [7] only considered the distribution of passengers on the platform waiting to board the train, leaving open the possibility of expanding what was done by these authors and studying the distribution of passengers inside the trains, which is the main objective of this study.

To study the distribution of passengers inside the train, the Level of Service (LOS) can be used. The LOS is introduced by transportation engineers to address the capacity of the design or the provision of space on the road, and assumes that the maximum achievable flow of vehicles is not desirable for all roads and could lead to planned congestion. However, this concept is not only used for roads but also to study the level of pedestrian flow that occurs in certain scenarios; that is, in areas where a certain domain of design is allowed, such as in urban trains, in which high levels of LOS can be provided with the consequent improvement of the pedestrian environment. It should also be mentioned that LOS corresponds to a quantitative indicator of the performance measurement that represents the quality of service, such as travel time, speed, delay, comfort, convenience, safety, cost, among others. The set of measurements used to determine the LOS in transport system is called a service measure [23,40].

In public transport, the LOS is used as a method to indicate the degrees of congestion and conflict in study areas such as flat areas, queues (waiting areas) or stairs, through general parameters such as speed, density or flow. Fruin [23] studied the behavior of passengers in some metro stations to obtain the capacity of a journey. With this information, he reported that by reducing the space the flow increases up to the limit capacity of the space and, in turn, the movement of passengers is reduced. That is, the higher the density, the lower the flow and speed of passengers. The *Highway Capacity Manual* [8] defines six levels for LOS, ranging from letter A to letter F, for each service measure. Level A represents the best operating conditions of the space from the passenger's point of view (free flow without conflicts). If the flow increases a greater density per m^2 is reached, generating a decrease in traffic speed in which a Level E is equivalent to the total capacity of the space. The worst case is reached in Level F where the critical density is exceeded. Fruin [23] used the LOS method to study the density of people who are moving or in waiting areas (for example, inside the train), according to the density, space, and percentage of occupancy in the vehicle.

In conclusion, the LOS is an effective methodology to study the different levels of density; however, it is not the most common method to analyze the distribution of passengers in such crowded spaces as the platform–train interface. Although it measures the density in the train or on the platform, it cannot be used as a specific indicator to measure the distribution of passengers in the different zones inside the train. Some authors have shown the need to include other parameters such as crowding, which can be used in parallel to the LOS. According to Evans and Wener [41], the overall density used in the LOS does not predict which space presents more interaction between passengers. The authors studied density, stress and commuting in trains where passengers must be seated next to others and found that the level of stress increased as the density went up. Kaparias et al. [42] studied the experience of pedestrians. The authors reported that existing studies have highlighted relevant factors that specifically affect the walking experience, such as Sarkar's [43] level of service which is based on safety, comfort and convenience, continuity, consistency system and attractiveness; or the study by Pikora et al. [44] in which the quality of walking depends on functional, safety, aesthetic and destination factors. The author evaluated the environment and the factors that specifically affect the experience of pedestrians based on questionnaires and regression models, following the PERS software [45].

3. Experimental Method

3.1. Variables Observed

According to Seriani and Fernández [46], the behavior of passengers is affected by three types of variables: firstly, physical variables are referred to as the dimensions of each circulation element to be studied (e.g., width and length of the train); secondly, operational variables are defined as the flow, movement, density, boarding and alighting times, among other variables that affect the behavior of passengers; thirdly, spatial variables are requested in which the passenger's behavior changes according to their environment (e.g., the use of platform edge doors between the platform and the train).

The physical and spatial variables were registered in 2017 from observations in existing stations of the London Underground network. In particular, the observations were based on two main stations: Green Park and Westminster stations (both on the Jubilee Line). These stations are located in the center of the city of London, in which high annual demand is reached (39.4 and 25.6 million trips per year, respectively [47]. Both stations have similar characteristics; however, the main difference between them is due to the fact that platform edge doors (PEDs) have been installed at Westminster station between the train and the platform, while Green Park station does not have PEDs.

From the observations at Green Park and Westminster stations in 2017, a series of experiments were carried out at the Pedestrian Accessibility Movement Environment Laboratory (PAMELA) of University College London (UCL). The mock-up at PAMELA represented a carriage of an urban train with two double doors 1600 mm wide, 20 seats, a horizontal space between the train and the platform of 90 mm, and a total surface area inside the wagon of 17.46 m^2 [7] (see Table 1 and Figure 1).

Table 1. Physical and spatial variables in PAMELA at UCL.

Variable	Symbology	Unit	Value
Train width	A_{train}	m	2.65
Train length	L_{train}	m	10.00
Platform width	$A_{platform}$	m	3.30
Platform length	$L_{platform}$	m	10.20
Door width	A_{doors}	m	1.60
Number of doors	N_{doors}	quantity	2.00
Vertical handrails	$N_{handrails}$	quantity	10.00
Central seats of the train	As_{Ctrain}	quantity	12.00
Train side seats	As_{Ltrain}	quantity	8.00
North and south side aisle area	$A_{aisleLN}$ and $A_{aisleLS}$	m^2	1.76 and 1.76
Central aisle area	A_{aisleC}	m^2	3.22
South and north central hall area	A_{hallCS} and A_{hallCN}	m^2	5.36 and 5.36
Total floor area	$A_{totalfloor}$	m^2	17.46

From Figure 1 it can be observed that 5 zones inside the train were defined, which were determined by the location of the seats, the vertical handrails, and the platform edge doors. These variables changed the behavior of passengers as they could modify the distribution of passengers within the train according to efficiency and safety:

- The central hall (CH) is the space located just at the moment of entering the train, which is limited by the seats and vertical handrail;
- The central aisle (CA) is the space between each central hall that the carriage has;
- The side aisles (SA) are the spaces that exist as a connection between the central hall and the seats;

- The central seats (CS) correspond to seats located in the center of the carriage (facing the central aisle), while side seats (SS) are located at the ends of the carriage (in front of the side aisles).

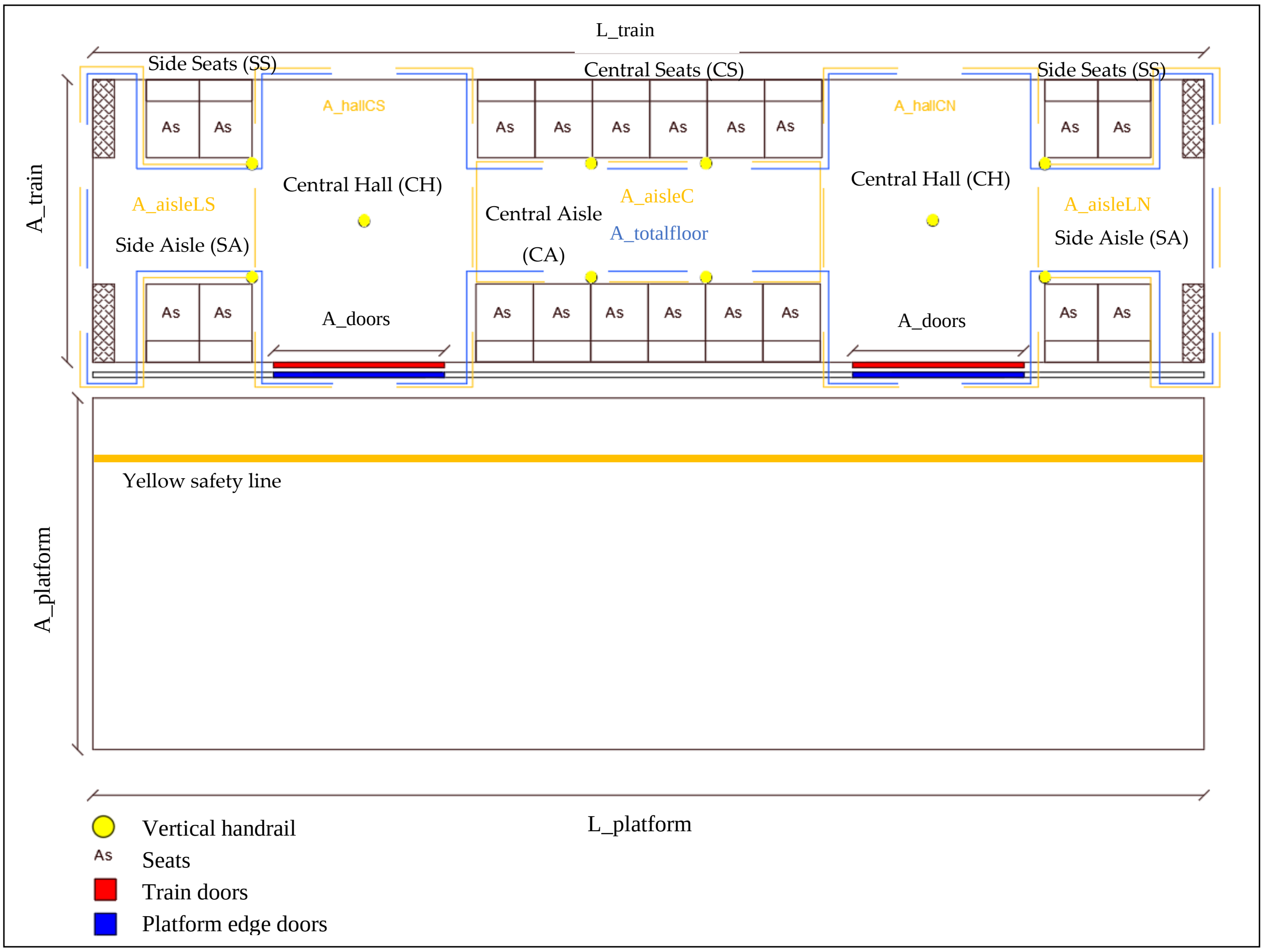

Figure 1. UCL PAMELA carriage to represent the boarding and alighting process.

At PAMELA the operational variables were defined before starting the experiments. The first group of operational variables was related to the distribution of passengers, which was defined as the behavior of passengers in terms of the movement they make within the different zones of the train for different levels of crowding. In this sense, movement is defined as the change in zone that the passenger made inside the train, while crowding is defined as the ratio between the number of passengers and the specific zone where they are located, but also as the percentage of space used by passengers in each zone inside the train.

To study the distribution of passengers inside the trains, three instants of time were defined (see Figure 2):

- The first instant of time was defined as the time before the doors opened. At this instant, the crowding level is considered for each zone inside the train;
- The second instant of time began when the doors opened and ended when the doors were closed. In this lapse of time, the number of passengers getting off is studied, which was defined as the passengers alighting from any zone inside the train towards the platform. Another variable observed was the number of passengers who remained inside the train (i.e., passengers who do not get off the train towards the platform, but they may or may not move within the train). At the second instant of time, the number

of passengers boarding was also addressed, defined as the passengers who were on the platform and ascend to some zone within the train;

- Finally, the third instant of time began when passengers entered the train and the doors closed. In this instant of time, the passengers who remained inside the train and those who boarded the train were counted.

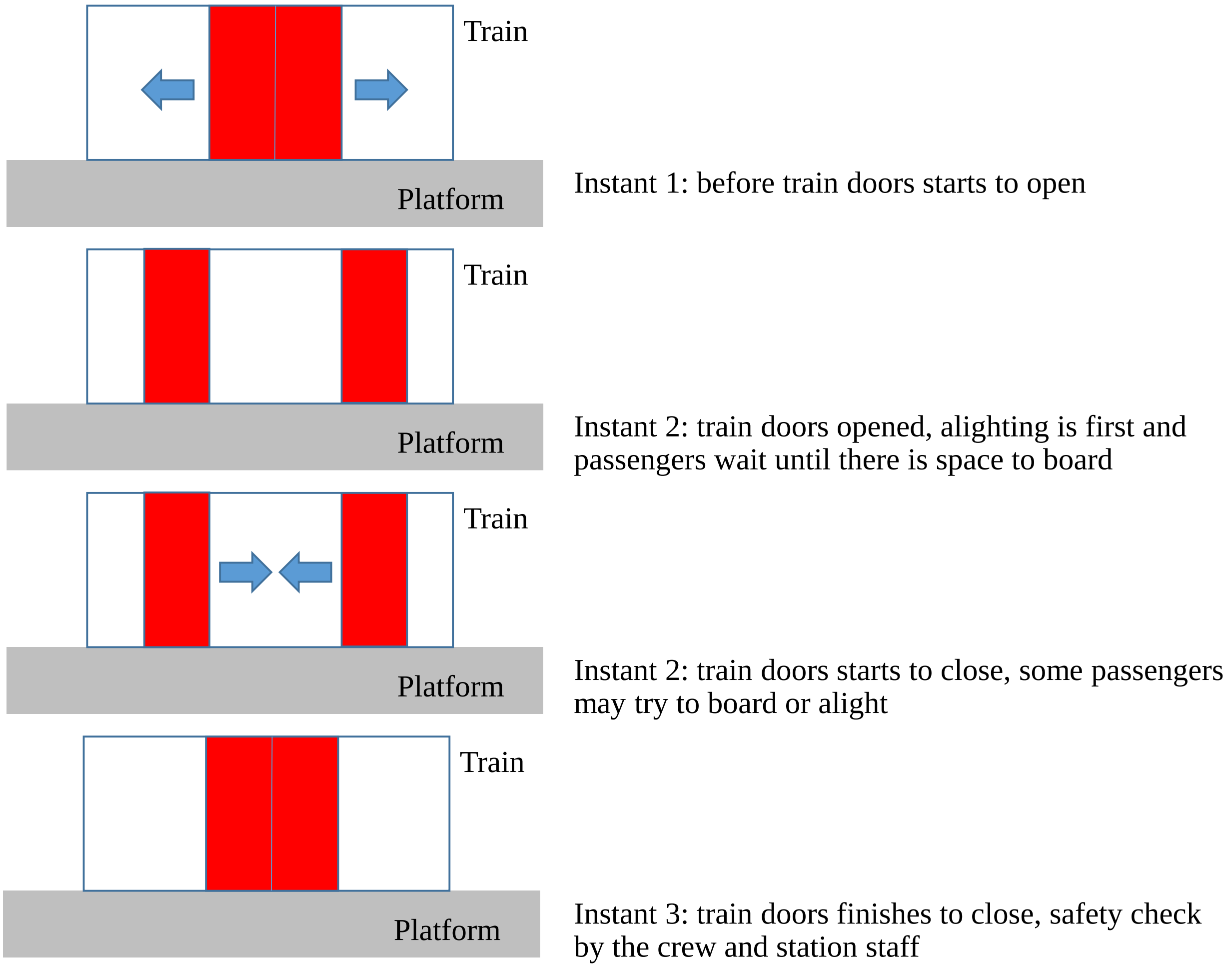

Figure 2. Instant of time defined in the experiments at PAMELA.

In the second and third instants of time the boarding and alighting time was analyzed, which measures the time it takes for passengers to get on and off from any zone inside the train to the platform. It is measured from the moment the first person crosses the yellow line and ends when the last person crosses the yellow line. The yellow line was located at the edge of the platform, which is a point of proximity to the train for the process of getting on and off.

The last operational variable observed in the second and third instants of time was the non-compliance with "let's get off the train before getting on the train". This included the behavior of passengers when interacting in the boarding and alighting process. This variable is studied based on how it affected the boarding and alighting time.

3.2. Scenarios

In this study, the scenarios were based on the experiments conducted by Seriani and Fujiyama [7] from PAMELA at UCL. Different scenarios were considered with a total of 110 passengers (see Table 2). Of the total passengers at the experiments (110 passengers), 46% (50 passengers) were men and 54% (60 passengers) were women. Most of them (78%)

were regular users of the London Underground. Regarding their ages, most of them (60%) were under 45 years old. The age group volunteers are detailed below:

- <24 years old: 15%;
- 25–34 years old: 26%;
- 35–44 years old: 19%;
- 45–59 years old: 27%;
- 60–64 years old: 7%;
- >65 years old: 7%.

Table 2. Scenarios to be studied at PAMELA at UCL.

Scenario	Symbology	Unit	Board	Alight	Remain Inside Carriage
0	LC0 (80, 20, 10)	Passenger	80	20	10
1	LC1 (20, 80, 10)	Passenger	20	80	10
2	LC2 (40, 40, 30)	Passenger	40	40	30
3	LC3 (40, 10, 60)	Passenger	40	10	60
4	LC4 (10, 40, 60)	Passenger	10	40	60
5	LC5 (20, 20, 70)	Passenger	20	20	70

The scenarios in Table 2 are classified according to three levels of crowding that depended on the number of passengers considered for the study and its analysis. The crowding level is defined in Table 3.

Table 3. Crowding classification for different case studies according to the scenario.

Crowding Level	Number of Passengers Considered [Passengers]
Low	≤50
Medium	51–80
High	≥81

Considering the different levels of crowding, a new method is proposed to study the distribution of passengers inside the train. This method consisted of observing the distribution of the passengers inside the train in the three instants of time, and 5 zones defined previously in Section 3.1. The method is developed by observing the videos of PAMELA from UCL (see Figure 2) for each scenario mentioned in Table 2. The two doors of the carriage are used for boarding and alighting simultaneously, in each scenario. The number of passengers getting on and off the train, their movements, distribution within the train, and the time it takes to board and alight are studied. The number of passengers who remained inside the train, their distribution and the movements that can be generated are also considered. In the PAMELA experiment at UCL, 12 runs were studied for each of the scenarios. In each run, passengers were assigned a number from No. 1 to No. 110 and caps of different colors (white for those getting off the train and red for those getting on). Those who remained inside the train did not use caps (see Figure 3).

It is important to mention that this method considered that passengers should get off the train before getting on the train, which refers to the fact that first all the passengers should alight, and then those who are waiting at the platform start boarding. However, it is considered a breach of such behavior when one or more passengers have boarded the train before the other passengers have alighted.

Figure 3. UCL experiments at PAMELA.

3.3. Indicators

The method used to measure the distribution of passengers in different scenarios begins with the division of the carriage at PAMELA of UCL into the five zones defined previously in Section 3.1 (the zones are central hall (CH), central aisle (CA), side aisles (SA), central seats (CS) and side seats (SS)). After the division is made, the distribution of passengers in the different zones of the train for the first instant of time is observed. Then, in the second instant of time, the movements are observed, from which data are collected on the number of people who get off, stay, and get on in the different zones of the train. It is carefully observed from which areas within the train the passengers get off, how those who remain in the different zones of the carriage are moved or redistributed, and subsequently, the data on the movements of those who board the train are collected. Finally, for the third instant of time, the location of the passengers who remained together inside the train with those who boarded is analyzed.

Other variables that are studied for the different scenarios correspond to the time it takes for passengers to get on and get off the train. As mentioned in Section 3.1, when the passengers alight the time begins to be measured from the moment the doors open and ends when the last passenger crosses the yellow line (located at the edge of the platform). The boarding time starts when the last person gets off (regardless of whether or not any passengers are getting on before) and stops when the last user boards the train.

In the first place, the level of crowding is compared to the LOS defined by Fruin [8] in the HCM [23]. This is analyzed through the 5 zones in which the train is divided. The analysis is done for the first, second and third instant of time in the scenarios mentioned previously in Section 3.2. The movement of passengers is compared by considering the probability of the movements that are generated from different zones of the train with different origins and destinations. The probability analyses help to identify which space inside the train is more congested, and therefore to better understand the distribution of passengers compared to the LOS which is based on average values of the whole train (see Table 4).

Table 4. Level of Service, density (pass/m^2) and space (m^2/pass) (Fruin [23]).

	Values for Moving Passengers in Flat Areas			Values for Passengers in Waiting Areas		Values for Both Cases
LOS	**Density** $[\frac{pass}{m^2}]$	**Space** $[\frac{m^2}{pass}]$	**Speed** $[\frac{m}{s}]$	**Density** $[\frac{pass}{m^2}]$	**Space** $[\frac{m^2}{pass}]$	**Occupation [%]**
A	≤0.31	≥3.24	≥1.3	≤0.82	≥1.21	0–30
B	0.31–0.43	2.32–3.24	1.27–1.3	0.82–1.07	1.21–0.93	30–40
C	0.43–0.72	1.39–2.32	1.22–1.27	1.07–1.53	0.93–0.65	40–60
D	0.72–1.08	0.93–1.39	1.14–1.22	1.53–3.57	0.65–0.28	60–80
E	1.08–2.17	0.46–0.93	0.76–1.14	3.57–5.26	0.28–0.19	80–100
F	≥2.17	≤0.46	≤0.76	≥5.26	≤0.19	≥100

4. Results

4.1. Passenger Distribution: The First Instant of Time

The first instant of time corresponded to the start of the videos and ends when the doors open. With the information collected from the 12 runs, the average density (passengers/m^2), the average occupancy level (%) and the LOS are calculated (Table 5).

Table 5. Density, Occupancy Level and Service Level, at the first instant of time.

	Density [Passengers/m^2]					**Occupation Level**					**Level of Service (LOS)**				
Stage	**CH**	**PC**	**SA**	**CS**	**SS**	**CH**	**PC**	**SA**	**CS**	**SS**	**CH**	**PC**	**SA**	**CS**	**SS**
LC0 (80,20,10)	0.47	1.01	1.63	4.02	4.44	9.0%	19.2%	31.1%	76.4%	84.4%	**A**	**B**	**D**	**E**	**E**
LC1 (20,80,10)	4.42	3.78	4.02	4.05	4.66	83.9%	71.8%	76.5%	77.1%	88.5%	**E**	**E**	**E**	**E**	**E**
LC2 (40,40,30)	3.00	3.18	2.79	4.68	4.66	57.0%	60.5%	53.1%	88.9%	88.5%	**D**	**D**	**D**	**E**	**E**
LC3 (40,10,60)	2.60	3.73	3.27	4.93	4.88	49.4%	70.8%	62.1%	93.8%	92.7%	**D**	**E**	**D**	**E**	**E**
LC4 (10,40,60)	4.31	5.23	4.92	5.22	5.10	81.9%	99.4%	93.6%	99.3%	96.9%	**E**	**E**	**E**	**E**	**E**
LC5 (20,20,70)	4.23	3.55	3.86	5.19	5.15	80.4%	67.4%	73.4%	98.6%	97.9%	**E**	**D**	**E**	**E**	**E**

First of all, it should be noted that for this instant of time the passengers considered are those who get off the carriage and those who remain on the train. To verify if the crowding level is high, medium, or low, the level of service (LOS) is observed in the central hall area (CH). The highest crowding level occurs in the LC1 (90 passengers), LC4 (100 passengers) and LC5 (90 passengers) scenarios; these passengers are distributed in other zones of the train in similar ways, reaching LOS = E. In medium-crowding level scenarios such as LC2 (70 passengers) and LC3 (70 passengers), although the number of passengers inside the train is the same (70 passengers), it can be seen that there is a higher density in the central aisle (CA) for LC3 than for LC2, This may be caused because in LC3 the number of passengers that remain inside the carriage is twice the amount considered in LC2, and therefore people tend to stay in places far from the train doors to avoid interaction with passengers getting off and on the carriage. For the low-crowding level scenario (LC0 = 30 passengers), several different LOS are seen. In this case, each central aisle and central hall have less occupancy, since the location preference depends mainly on comfort or safety, and they do not necessarily seek to locate near the doors to have a shorter alighting time. This is caused because it is easy to move due to the large free space that exists inside the carriage.

Regarding the descriptive statistical analysis carried out for each of the scenarios (considering the information collected from the 12 repetitions), Table 5 shows the average density presented by the different scenarios; it was expected, as mentioned above, that the average in high-crowding level scenarios such as LC1, LC4 and LC5 would have a higher value of density than the average in zones such as central hall (HC), central aisle (CA) and side aisle (SA). This is followed by medium-crowding level scenarios like LC2 and LC3. The low-crowding level scenario like LC0 presented the lowest density. However, it is observed that the average density in the central seating zone (CS) and side seats (SS) does not vary greatly according to each scenario (maintaining LOS = E). Results show that all available seats are generally used. This can be explained by the fact that passengers always prefer to remain seated regardless of the amount of space inside the train, seeking the comfort and safety that these areas represent.

On the other hand, it can be seen that the sample variance and standard deviation in each of the scenarios do not have excessively large values, which means that the data do not behave in a dispersed manner; this shows that in each repetition the location of the passengers does not vary significantly. Likewise, the highest variance of the sample and standard deviation occurs in the central hall area in the LC4 scenario. This scenario is of high crowding level and with a greater similarity between the participants who get off (40 passengers) and remain (60 passengers). Another potential cause is that the interaction between those who get off and stay is high, and therefore a greater uncertainty for passengers is reached. These values are explained due to the range of values that occurs in the different zones of each of the scenarios.

4.2. Passenger Distribution: The Second Instant of Time

The second instant of time begins when the doors open and ends when they close. This section deals with the results of the movements made by the passengers for this instant of time and their respective analyses. Next, the behavior of passengers getting off the train towards the platform is studied, with the importance of showing which are the areas where more passengers get off and their associated behaviors. Then, the studies and analyses were carried out to obtain the probability of movement from each zone. This probability is calculated according to the information collected, as the passengers who move from or to a specific zone divided by the total number of passengers per scenario

Given the probabilities calculated in Table 6, it can be seen that the low-crowding scenario LC0 (passengers who get off and stay inside the train) is the only scenario in which the greatest probabilities of alighting originate in zones central seating areas (CS) and side seats (SS). This can be explained since there is no need for passengers to be near the train doors as there is enough space to move from any zone when getting off the carriage, and therefore, comfort and safety are prioritized. This is contrary to what happens in the medium-crowding level (LC2 and LC3) and high-crowding level (LC1, LC4 and LC5) scenarios, in which the movement is more complex and where there is a greater probability of alighting from the central hall (CH). This is because the passenger prioritizes efficiency when getting off the carriage in terms of time, and therefore this is the zone that allows it because it is the closest to the train doors.

Table 6. Probability of zones from which passengers get off for the second instant of time.

Scenario	Total Alighting per Stage [Passengers]	Probability of Getting off the Train Towards the Platform				
		CH	CA	SA	CS	SS
LC0 (80,20,10)	240	0.117	0.104	0.163	0.375	0.242
LC1 (20,80,10)	960	0.553	0.141	0.147	0.094	0.066
LC2 (40,40,30)	480	0.619	0.154	0.067	0.079	0.081
LC3 (40,10,60)	120	0.342	0.125	0.183	0.133	0.217
LC4 (10,40,60)	480	0.592	0.106	0.158	0.079	0.065
LC5 (20,20,70)	240	0.308	0.267	0.158	0.192	0.075

Table 7 shows the probabilities of movement of those who stayed inside the carriage. The probability is obtained considering the ratio between those passengers who moved from their origin or destination and the total number of passengers who moved. Table 7 shows the probability for those passengers who moved from their origin in which the movements take place for these passengers, followed by the probability for those passengers who moved considering their zone of the destination. Table 7 shows, in all the scenarios studied, the zone where a greater change in movements is produced from the central hall (CH), which has the benefit of greater proximity to all the other zones and toward the doors of the train. The other zones such as the central aisle (CA) and side aisle (SA) reached fewer movements. On the other hand, from central seats (CS) and side seats (SS), the probability of origin is almost zero, but the destination reached the highest probability. This means that passengers who are seated did not change their positions due to comfort reasons, and if there was a seat available it was rapidly desired by passengers who wanted to be seated rather than standing inside the train.

Table 7. Probability of movement with origin and destination of passengers who remained inside the train.

		Probability Movement Originating in					Probability Movement with Destination in				
Scenario	**Total Passengers Who Moved**	**CH**	**CA**	**SA**	**CS**	**SS**	**CH**	**CA**	**SA**	**CS**	**SS**
LC0 (80,20,10)	46	0.57	0.09	0.30	0.04	0.00	0.02	0.04	0.00	0.52	0.41
LC1 (20,80,10)	60	0.53	0.15	0.32	0.00	0.00	0.08	0.00	0.00	0.53	0.38
LC2 (40,40,30)	92	0.45	0.21	0.35	0.00	0.00	0.20	0.01	0.00	0.40	0.39
LC3 (40,10,60)	45	0.44	0.16	0.40	0.00	0.00	0.00	0.00	0.00	0.40	0.60
LC4 (10,40,60)	177	0.43	0.29	0.28	0.00	0.00	0.36	0.13	0.15	0.20	0.16
LC5 (20,20,70)	120	0.71	0.23	0.07	0.00	0.00	0.00	0.53	0.00	0.35	0.12

Table 8 shows that for the passengers who board, the greatest probability occurs in the movement towards the central hall zone (CH), reaching a range between 0.233 (LC1 20,80,10) and 0.704 (LC3 40,10,60). This is caused because of the proximity and the large space that is presented. In the CH, there is a low crowding level and a low level of occupation of those passengers who remained inside the train. Therefore, the probability that passengers will go to a zone increases if the density in that sector is lower.

Table 8. Probability of passengers boarding for the second instant of time.

		Probability of Boarding the Train from the Platform				
Scenario	**Total Boardings per Scenario [Passengers]**	**CH**	**CA**	**SA**	**CS**	**SS**
LC0 (80,20,10)	960	0.509	0.154	0.174	0.106	0.056
LC1 (20,80,10)	240	0.233	0.071	0.104	0.379	0.213
LC2 (40,40,30)	480	0.592	0.173	0.171	0.035	0.029
LC3 (40,10,60)	480	0.704	0.121	0.148	0.015	0.013
LC4 (10,40,60)	120	0.467	0.275	0.183	0.033	0.042
LC5 (20,20,70)	240	0.600	0.167	0.183	0.025	0.025

Another factor that influences the calculated probabilities is the preference of the people who have to use the central seating areas (CS) and side seats (SS), whenever there is availability. First, if there is availability in these zones, boarding passengers will be moved to those areas. Secondly, passengers will prefer to move to the central hall (CH) due to the efficiency and proximity to the doors that this area provides. Finally, passengers will move to areas such as the central aisle (CA) and side aisle (SA), with a greater probability of boarding in those cases of low occupancy level.

4.3. Passenger Distribution: The Third Instant of Time

The third instant of time begins when passengers board and the doors close. For this instant of time, the passengers who boarded and those who remained were considered, where the average density of each scenario, the average occupancy level, and the associated service level were calculated (see Table 9).

Table 9. Density, Occupancy Level and Service Level, in the third instant of time.

	Density [Passengers/m^2]					Occupation Level					Level of Service (LOS)				
Scenario	**CH**	**PC**	**SA**	**CS**	**SS**	**CH**	**PC**	**SA**	**CS**	**SS**	**CH**	**PC**	**SA**	**CS**	**SS**
LC0 (80,20,10)	3.86	4.14	4.33	5.26	5.26	73.5%	78.7%	82.4%	100.0%	100.0%	**E**	**E**	**E**	**F**	**F**
LC1 (20,80,10)	0.51	0.49	0.83	5.26	5.26	9.8%	9.3%	15.8%	100.0%	100.0%	**A**	**A**	**B**	**F**	**F**
LC2 (40,40,30)	2.72	2.95	3.22	5.26	5.26	51.7%	56.1%	61.2%	100.0%	100.0%	**D**	**D**	**D**	**F**	**F**
LC3 (40,10,60)	4.75	4.66	4.00	5.26	5.26	90.3%	88.6%	76.1%	100.0%	100.0%	**E**	**E**	**E**	**F**	**F**
LC4 (10,40,60)	2.44	4.04	3.08	5.26	5.26	46.4%	76.8%	58.5%	100.0%	100.0%	**D**	**E**	**D**	**F**	**F**
LC5 (20,20,70)	4.11	3.88	3.81	5.26	5.26	78.2%	73.8%	72.5%	100.0%	100.0%	**E**	**E**	**E**	**F**	**F**

According to the densities at this instant of time, it can be seen that the high-crowding level scenarios (sum of passengers who board and remain on the train) are LC0 (90 passengers), LC3 (100 passengers) and LC5 (90 passengers). The medium-crowding level scenarios are reached in LC2 (70 passengers) and LC4 (70 passengers). Finally, LC1 (30 passengers) is considered a low-crowding scenario. Similar to the analysis carried out for the first instant of time, it is shown that the crowding categorization of each scenario (high, medium or low density) can be corroborated with the level of service (LOS) that occurs in the area of the central hall (HC) because this is the busiest area with the highest interaction between passengers.

It can be seen from the LOS that in the LC0, LC3 and LC5 scenarios they are LOS = E in the central hall (HC), central aisle (CA) and side aisle (SA) zones, which demonstrates a uniform distribution throughout the train according to the space available. Moreover, it is observed that although LC2 and LC4 are medium-density scenarios for this instant of time, they differ in the LOS that is presented in the central corridor area, in which in the case of LC2 it is LOS D and in LC4 is LOS E. This behavior can occur mainly due to the number of passengers that remain inside the train, in which LC4 has twice that of LC2, and these passengers are located mostly in this area (center aisle) to move away from the train doors, avoiding high interactions with boarding passengers.

In the LC1 scenario, the density and level of occupation are low in almost all zones. Having such availability of space allows passengers to choose the location based on comfort, safety and efficiency, thus facilitating the passenger's journey. However, there is certain behavior that is repeated with the other scenarios and deals with the LOS that is presented in the central seating areas (SA) and side seats (SS) that have 100% occupancy being of LOS F. This behavior responds to the need for passengers to be comfortable and safe on their trip, even if this means having a high density.

A descriptive statistical analysis of the aforementioned scenarios is done according to the information collected. The average of the different scenarios is observed, in which the highest values are in the high-crowding level scenarios (LC0, LC3 and LC5). In these scenarios, the highest averages are in the central hall, central aisle, and side aisle areas, because these are the sectors with the greatest availability. The medium-crowding level scenarios (LC2 and LC4) have lower averages due to the level of occupation in them. However, as mentioned above, it is observed that for LC4 the average observed in the central aisle is greater than in LC2. The low-crowding level scenario LC1 is the one with the lowest averages in the central hall, central aisle, and side aisle zones. It is also observed that the variance and standard deviation in the different zones of the LC0, LC1, LC2, LC3 and LC5 scenarios do not vary much between them and do not have high values either, which means that the data do not behave in a scattered way, showing that the behavior of people does not change much in each of the repetitions. However, in LC4 the opposite occurs with a variance of 17.06 [passengers/m^2] and a standard deviation of 4.13 [passengers/m^2] in the central hall area. This may be because there is greater variability of scenarios, considering that passengers did not know how many people will board the train, and therefore they were exposed to different cases such as many passengers boarding (worst case) or few passengers (best case). Thus, passengers needed to accommodate their position considering the unknown exact location of the greatest number of passengers, which may affect their convenience to feel comfortable, safe or efficient.

4.4. Boarding and Alighting Time

This section shows the times it takes for passengers to get off and on the carriage. The alighting time begins when the doors open and ends when the last passenger to get off crosses the yellow line (at the edge of the platform). Boarding time begins when the last passenger getting off crosses the yellow line and ends when the last passenger boards.

Table 10 shows that the time of the greatest alighting time is in the LC1 scenario because it has a greater number of people who want to get off (80 passengers per run). Then it is observed that the second scenario, which has the greatest alighting time, is LC4 followed by LC2; this is because they reached the highest number of passengers getting off (40 passengers). However, the wide difference in the times it takes to get off is because the density in LC4 is high for the first instant of time (100 passengers who get off and stay inside the carriage) and for LC2 it is medium (70 passengers who get off and stay inside the carriage).

Table 10. Average number of passengers getting off and on, and boarding and alighting times.

Scenario	Total Passengers Who Alighted [Pass]	Total Passengers Who Boarded [Pass]	Alight in Average [Pass]	Board in Average [Pass]	Average Alighting Time [s]	Average Boarding Time [s]
LC0 (80,20,10)	240	960	20	80	12.87	28.63
LC1 (20,80,10)	960	240	80	20	30.36	7.42
LC2 (40,40,30)	480	480	40	40	21.14	16.45
LC3 (40,10,60)	120	480	10	40	7.90	24.43
LC4 (10,40,60)	480	120	40	10	24.92	5.04
LC5 (20,20,70)	240	240	20	20	16.44	11.51

It is also seen from Table 10 that the scenario is LC5 and then LC0 that reached a lower alighting time. In these cases, the number of passengers getting off is the same (20 passengers); however, in the case of LC5, the density in the first instant of time reached a high value (90 passengers getting off and staying inside the carriage), while in LC0 it is reached a low density (30 passengers getting off and staying inside the carriage). Finally, the lowest alighting time is obtained in the LC3 scenario, which is the scenario with the least number of people who want to get off (10 passengers).

Once this analysis has been carried out, it can be concluded that the alighting time depends mainly on two factors: First and foremost, the number of passengers getting off, that is, the greater the number of passengers getting off, the longer the time it takes to get off. Second, and less decisive, is the density of passengers inside the train in the first instant of time (i.e., who wanted to alight and stay inside the train), since the density is higher and the longer the time it takes for passengers to get off.

In the case of boarding, it can be seen that the scenario in which passengers take longer to board is in LC0, since more passengers want to board (80 passengers per repetition) compared to the other scenarios. The second scenario in which passengers take longer to board is LC3 followed by LC2. Although the passengers who want to board are the same (40 passengers), it differs in that the LC3 scenario has a greater number of passengers who stayed in the second instant of time (60 passengers) compared to LC2 (30 passengers). Then we have LC5 and LC1, which have the same number of people boarding (20 passengers), but they differ in that there is a greater number of people staying at the second instant of time for LC5 (70 passengers) than for LC1 (10 passengers). Finally, the scenario in which it takes less time for passengers to board is in LC4 (10 passengers).

Given these results and similar to the alighting time, it is shown that the boarding time depends mainly on two factors: First and foremost, is the number of passengers boarding, that is, the greater the number of passengers, the longer the time it takes to board. In second place and less decisive, are the passengers who remained inside the train in the second instant of time, since the greater the number of passengers who remained inside the train, the greater the time it takes for passengers to board.

Next, descriptive statistical analysis is developed. It can be seen that the highest average boarding time occurs in the LC0 scenario and in the alighting time for LC1. This is because in LC0 there are more people boarding than alighting, which is the opposite of LC1 (i.e., more people alighting than boarding). It is also observed that the lowest average corresponds to a smaller number of passengers, which occurs in the case of boarding in LC4 with a time of 5.7 [s] with 10 passengers, while in the case of alighting it is in the LC3 scenario with a time of 9.74 [s] for 10 passengers. It can also be reported that the standard deviation in all scenarios except LC3 is larger for alighting time than for boarding time. This is explained by the greater dispersion of data that occurs during the alighting, which may be due to the complications that there are to moving inside the train and getting off (because the passengers who are on the platform generally obstruct the normal alighting flow). However, this problem does not arise when passengers board the train, because the people who stay inside the train avoid interacting with those who board, looking for comfortable and safe areas far from the central hall area (area closest to the doors). This is evident when the boarding and alighting times are compared for the scenarios with the same number of people boarding and alighting, as in this case of scenario LC2 (40 passengers boarding and 40 passengers alighting) and LC5 (20 passengers boarding and 20 passengers alighting). Table 10 clearly shows that the time it takes for passengers to get on is less than to get off.

4.5. Behavior of "Let's Get off the Train before Getting on the Train"

This section analyses how the "let's get off the train before getting on the train" behavior affects the time it takes for passengers to board and alight. This behavior does not hold when there is at least one person getting on the train before everyone has gotten off. It is observed which are the scenarios where this non-compliance is more common, and which are the factors that affect it.

With the information collected, it was observed whether the behavior "let's get off the train before getting on the train" was fulfilled or not fulfilled. Behavioral data were recorded as a binary value (yes or no), depending on whether all passengers got off before the first passenger to board is met or not met. Table 11 below shows the number of compliances and non-compliances for each of the 12 runs per scenario and the average times in each case for all scenarios.

Table 11. Effect of non-compliance of the "let's get off the train before getting on the train" behavior.

Scenario	Total Compliance "Let's Get off before Getting on"	Total Non-Compliances "Let's Get off before Getting on"	Average Time of Compliance "Let's Get off before Getting on" [s]	Average Time Non-Compliance "Let's Get off before Getting on" [s]
LC0 (80,20,10)	7	5	40.50	42.87
LC1 (20,80,10)	7	5	37.02	38.82
LC2 (40,40,30)	8	4	36.01	37.95
LC3 (40,10,60)	9	3	29.59	31.94
LC4 (10,40,60)	10	2	29.82	30.89
LC5 (20,20,70)	11	1	28.41	29.51

In Table 11 it is observed that the highest number of non-compliances occurs in the scenarios with the greatest interaction (boarding and alighting), in which the LC0 (100 passengers) and LC1 (100 passengers) scenarios lead these cases, followed by LC2 (80 passengers), LC3 (50 passengers), LC4 (50 passengers) and LC5 (40 passengers). A potential cause of this is due to the uncertainty that exists in finding a space inside the train and not being left out of it. It is seen in the same way that for the scenarios that have the same interaction, such as LC0 with LC1 and LC3 with LC4, the times will be greater when more passengers board than those who alight, since those who board the train are responsible for the compliance of this behavior. It is also observed that the interaction times when the behavior is breached are always greater than when it is fulfilled, which makes the operation of the train–platform interface less efficient. This variation is seen in Table 11, where the average times vary between 1 to 2 s when this behavior is breached. Given these results, it can be concluded that compliance with this behavior is essential for the efficiency of the platform–train interface.

5. Conclusions

The distribution of passengers inside the train is detrimental to the normal functioning of the train–platform interface in terms of comfort, safety and efficiency. Therefore, this allows us to study the effect of crowds (in terms of densities) on passenger behavior, which was carried out through the observation of videos from the PAMELA laboratory at UCL, analyzing the movement of these passengers.

Through the method developed, in which the train is divided into five zones and the results are analyzed in three instants of time, it is evident how passengers are distributed at different density levels and the behaviors they adopt in each case. When there is a high level of crowding inside the train (LC1, LC4 and LC5), those who alight tend to locate in areas close to the doors such as the central hall area to get off more efficiently in terms of time. However, those who stay on the train prefer areas away from the doors, such as the central aisle or side aisles. This allows those getting off and staying on the train to interact less with those getting on. As the crowding level decreases, this behavior changes to such an extent that for low densities (LC0) the area in which the passenger is positioned is mainly related to comfort and safety, more than to any other factor. This is due to the space in the train that allows passengers to move more easily when getting off, staying, and changing positions.

In scenarios with medium and low crowding levels, passengers who remain on the train often tend to change their position looking for comfort, safety, or efficiency. For these reasons, the behaviors they acquire are different due to their need and the density of passengers that arise. In all situations, most of the movements originate from the central hall area, which confirms that passengers avoid interacting with those who board, and therefore they go to spaces far from the train doors. In addition, it is observed that the most common destination areas for those who move are the lateral and central seats, if there is space availability, due to the comfort that these places provide.

The most important factors are comfort and safety for those who board the train. This behavior changes due to the density level inside the train in all scenarios. According to the results obtained and the method developed, the discretization of the space inside the train is more representative of the interaction than average values of density used mainly by Fruin's Level of Service to design and manage the platform–train interface. There is certain behavior that directly affects the interaction of passengers getting on and off; this occurs when the "let's get off the train before getting on the train" behavior is breached. This is caused by passengers boarding, which affects the normal operation of the train–platform interface since it does not allow people to get off smoothly, and therefore the interaction between those getting on and off takes 1 to 2 more seconds. The scenarios in which this behavior is breached the most are those in which there is greater interaction, which can be generated due to the greater uncertainty of finding more comfortable and safer places, such as the central and side seats.

All the conclusions developed above show that passengers do have different behaviors in different density scenarios, which generally negatively affects the proper functioning of the train–platform interface, whose objective is to provide comfort, safety, and efficiency to its users. Future research requires considering other types of passengers at the interface, such as passengers with reduced mobility or disabilities. These investigations will require new observation-based experiments in a larger number of types of subway stations, which will allow to conduct of some statistical analyses to verify the significance of the results.

Author Contributions: Conceptualization, T.F. and S.S.; methodology, S.S., J.M.B. and V.A.; software, J.M.B.; validation A.V., V.A. and L.J.; formal analysis, S.S. and J.M.B.; investigation, V.A., J.M.B. and S.S.; resources, S.S., T.F. and H.P.; data curation, J.M.B. and S.S.; writing—original draft preparation, S.S. and V.A.; writing—review and editing, M.V. and A.P.; visualization, J.M.B.; supervision, S.S.; project administration, S.S., T.F. and H.P.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study is partially supported by FONDECYT Project 11200012 and FONDEF Project ID22I10018. Both projects are from ANID, Chile.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Universidad de los Andes (protocol code CEC202089 approved on 23 October 2020).

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the volunteers who participated in the experiments. In particular, the authors are thankful for the collaboration between researchers from University College London (UCL) and Pontificia Universidad Catolica de Valparaiso, who had access to the video records of the experiments at UCL's Pedestrian Accessibility Movement Environment Laboratory (PAMELA).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ogryzek, M.; Adamska-Kmieć, D.; Klimach, A. Sustainable transport: An efficient transportation network—Case study. *Sustainability* **2020**, *12*, 8274. [CrossRef]
2. Palmqvist, C.W. Excess probability of dwell time delays from train meets and passes. *J. Rail Transp. Plan. Manag.* **2022**, *21*, 100298. [CrossRef]
3. *Transport for London Annual Report and Statement of Accounts 2020/21*; Transport for London: London, UK, 2021. Available online: https://content.tfl.gov.uk/tfl-annual-report-9-august-2021-acc.pdf (accessed on 14 February 2022).
4. *Transport for London Travel in London Report 14*; Transport for London: London, UK, 2021. Available online: https://content.tfl.gov.uk/travel-in-london-report-14.pdf (accessed on 14 February 2022).
5. Beramendi, M.R.; Romero-Gianotti, M.D.L.Á. Perception of (in) regulatory compliance in the underground of the City of Buenos Aires. *EURE* **2022**, *48*. [CrossRef]

6. RSSB. *RSSB Platform Train Interface Strategy*; Rail Safety and Standards Board: London, UK, 2015.
7. Seriani, S.; Fujiyama, T. Modeling the distribution of passenger waiting to board the train at metro station. *J. Rail Transp. Plan. Manag.* **2019**, *11*, 100141.
8. HCM. *Highway Capacity Manual Virginia Department of Transportation*; Highway Capacity Manual; Research Board of the National Academy of Sciences: Washington DC, USA, 2010.
9. Seriani, S.; Fujiyama, T.; Holloway, C. Exploring the pedestrian level of interaction on platform conflict areas at metro stations by real-scale laboratory experiments. *Transp. Plan. Technol.* **2017**, *40*, 100–118. [CrossRef]
10. Seriani, S.; Fernandes, V.A.; Moraga, P.; Cortes, F. Experimental Location of the Vertical Handrail to Improve the Accessibility of Wheelchair Passengers Boarding and Alighting at Metro Stations—A Pilot Study. *Sustainability* **2022**, *14*, 9224. [CrossRef]
11. Ortuzar, J.D.; Willumsen, L.G. *Modeling Transport*, 4th ed.; Wiley: Chichester, UK, 2011.
12. Seriani, S.; Fernández, R.; Oyanedel, C. The impact of gap dimensions on passengers boarding and alighting using different mobility aids at railway stations by laboratory experiments. *Int. J. Rail Transp.* **2021**, *9*, 186–202. [CrossRef]
13. RSSB. *RSSB Management of on-Train Crowding Final Report*; Rail Safety and Standards Board: London, UK, 2008.
14. Webb, J.D.; Weber, M.J. Influence of sensory abilities on the interpersonal distance of the elderly. *Environ. Behav.* **2003**, *35*, 695–711. [CrossRef]
15. Hoogendoorn, S.P.; Daamen, W. Pedestrian behavior at bottlenecks. *Transp. Sci.* **2005**, *39*, 147–159. [CrossRef]
16. Cox, T.; Houdmont, J.; Griffiths, A. Rail passenger crowding, stress, health and safety in Britain. *Transp. Res. Part A Policy Pract.* **2006**, *40*, 244–258. [CrossRef]
17. Still, K. *Introduction to Crowd Science*; CRC Press: Boca Raton, FL, USA, 2014.
18. Schmidt, D.E.; Keating, J.P. Human crowding and personal control: An integration of the research. *Psychol. Bull.* **1979**, *86*, 680. [CrossRef] [PubMed]
19. Sakuma, T.; Mukai, T.; Kuriyama, S. Psychological model for animating crowded pedestrians. *Comput. Animat. Virtual Worlds* **2005**, *16*, 343–351. [CrossRef]
20. Hall, E. *The Hidden Dimension*; Doubleday: Garden City, NY, USA, 1966; Volume 14, pp. 103–124.
21. Sommer, R. *Personal Space: The Behavioral Basis of Design*; Prentice Hall: Englewood Cliffs, NJ, USA, 1969.
22. Lam, W.H.; Cheung, C.Y.; Lam, C.F. A study of crowding effects at the Hong Kong light rail transit stations. *Transp. Res. Part A Policy Pract.* **1999**, *33*, 401–415. [CrossRef]
23. Fruin, J.J. *Designing for Pedestrians*, 1st ed.; University Microfilms: New York, NY, USA, 1971.
24. Pushkarev, B.; Zupan, J. *Urban Space for Pedestrians*; The MIT Press: Cambridge, MA, USA, 1975.
25. Gérin-Lajoie, M.; Richards, C.; McFadyen, B. Characteristics of personal space during obstacle circumvention in physical and virtual environments. *Gait Posture* **2007**, *23*, 239–247. [CrossRef] [PubMed]
26. Daamen, W.; Hoogendoorn, S. Controlled experiments to derive walking behavior. *Eur. J. Transp. Infrastruct. Res.* **2003**, *3*, 39–59.
27. Tirachini, A.; Henser, D.A.; Rose, J.M. Six passengers per square meter: Effects of overcrowding on public transport supply, user welfare and demand estimation. In Proceedings of the XVI Chilean Congress of Transportation Engineering, Santiago, Chile, 21–25 October 2013; pp. 1–15.
28. Oliveira, L.C.; Fox, C.; Birrell, S.; Cain, R. Analysing passengers' behaviours when boarding trains to improve rail infrastructure and technology. *Robot. Comput.-Integr. Manuf.* **2019**, *57*, 282–291. [CrossRef]
29. Daamen, W.; Lee, Y.C.; Wiggenraad, P. Boarding and alighting experiments: Overview of setup and performance and some preliminary results. *Transp. Res. Rec.* **2008**, *2042*, 71–81. [CrossRef]
30. Daamen, W.; de Boer, E.; de Kloe, R. Assessing the gap between public transport vehicles and platforms as a barrier for the disabled: Use of laboratory experiments. *Transp. Res. Rec.* **2008**, *2072*, 131–138. [CrossRef]
31. Fernández, R.; Valencia, A.; Seriani, S. On passenger saturation flow in public transport doors. *Transp. Res. Part A Policy Pract.* **2015**, *78*, 102–112. [CrossRef]
32. Fujiyama, T.; Childs, C.; Boampong, D.; Tyler, N. Investigating ramp gradients for humps on railway platforms. *In Proc. Inst. Civ. Eng.-Munic. Eng.* **2015**, *168*, 150–160. [CrossRef]
33. Holloway, C.; Thoreau, R.; Roan, T.R.; Boampong, D.; Clarke, T.; Watts, D.; Tyler, N. Effect of vertical step height on boarding and alighting time of train passengers. *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit* **2016**, *230*, 1234–1241. [CrossRef]
34. Thoreau, R.; Holloway, C.; Bansal, G.; Gharatya, K.; Roan, T.R.; Tyler, N. Train design features affecting boarding and alighting of passengers. *J. Adv. Transp.* **2016**, *50*, 2077–2088. [CrossRef]
35. Seriani, S.; de Ana Rodríguez, G.; Holloway, C. Combined effect of platform edge doors and level access on boarding and alighting process in London Underground. *Transp. Res. Rec.* **2017**, *2648*, 60–67. [CrossRef]
36. Seriani, S.; Fernandez, R.; Luangboriboon, N.; Fujiyama, T. Exploring the effect of boarding and alighting ratio on passengers' behavior at metro stations by laboratory experiments. *J. Adv. Transp.* **2019**, *2019*, 6530897. [CrossRef]
37. Seriani, S.; Fernandez, R. Pedestrian traffic management of boarding and alighting in metro stations. *Transp. Res. Part C Emerg. Technol.* **2015**, *53*, 76–92. [CrossRef]
38. Seriani, S.; Fujiyama, T. Experimental study for estimating the passenger space at metro stations with platform edge doors. *Transp. Res. Rec.* **2018**, *2672*, 307–315. [CrossRef]
39. Valdivieso, J.; Seriani, S. Study of the Space Occupied by a Wheelchair User at Metro de Santiago Platforms by Laboratory Experiments. *J. Adv. Transp.* **2021**, *2021*, 1789241. [CrossRef]

40. Sabando, I.F. Determination of the Level of Service in Urban Streets. Ph.D. Thesis, Federico Santa Maria Technical University, Valparaiso, Chile, 2018.
41. Evans, G.W.; Wener, R.E. Crowding and personal space invasion on the train: Please don't make me sit in the middle. *J. Environ. Psychol.* **2007**, *27*, 90–94. [CrossRef]
42. Kaparias, I.; Bell, M.G.H.; Gosnall, E.; Abdul-Hamid, D.; Dowling, M.; Hemnani, I.; Mount, B. Assessing the pedestrian experience in public spaces. In Proceedings of the 91st Transportation Research Board Annual Meeting, Washington, DC, USA, 22–26 January 2012.
43. Sarkar, S. Determination of service levels for pedestrians with European examples. *Transp. Res. Rec. J. Transp. Res. Board* **1993**, *1405*, 35–42.
44. Pikora, T.; Jamrozik, K.; Knuiman, M.; Giles-Corti, B.; Donovan, R. Developing a reliable audit instrument to measure the physical environment for physical activity. *Am. J. Prev. Med.* **2002**, *23*, 187–194. [CrossRef]
45. Allen, D. PERS v2: Auditing public spaces and interchange spaces. In Proceedings of the Walk21-6th International Conference on Walking in the 21st Century, Zurich, Switzerland, 21–24 September 2005.
46. Seriani, S.; Fernández, R. Planning guidelines for metro–bus interchanges by means of a pedestrian microsimulation model. *Transp. Plan. Technol.* **2015**, *38*, 569–583. [CrossRef]
47. Transport for London London Data Store. *London Underground Performance Reports*; Transport for London: London, UK, 2017. Available online: https://data.london.gov.uk/dataset/london-underground-performance-reports (accessed on 15 February 2022).