REAL-SCALE LABORATORY EXPERIMENTS TO STUDY PASSENGER BEHAVIOUR BY MARKINGS IN FRONT OF PUBLIC TRANSPORT DOORS

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RESUMEN

En este artículo se busca encontrar la mejor demarcación en andenes para gestionar el flujo de pasajeros en puertas del transporte público. El objetivo es hacer más eficiente los procesos de carga y descarga, disminuir el tiempo de transferencia de pasajeros o *dwell time* y, por consiguiente, reducir las demoras en estaciones. El estudio se hizo en el Laboratorio de Dinámica Humana (LDH) de la Universidad de los Andes (Santiago-Chile), el cual cuenta con una maqueta a escala real del hall de un vehículo de transporte público. Mediante cámaras en diferentes ángulos se registraron procesos de subida y bajada para distintos esquemas de demarcación del andén. Como resultado se obtuvo tanto el mejor esquema de demarcación, así como como aquel menos eficiente.

Palabras claves: transporte público, pasajeros, comportamiento

ABSTRACT

In this article we studied the best marking scheme on platforms to manage the behaviour of passengers in front of public transport doors. The study was carried out in the Human Dynamics Laboratory (HDL) at Universidad de los Andes, Chile, which has a real-scale model of the hall of a public transport vehicle and its adjacent platform. The research objective is to make boarding and alighting processes more efficient to reduce vehicle delays at stations. In order to achieve this objective, five marking schemes on the platform were studied in our laboratory. As a result, both the best scheme as well as the least efficient were obtained. We are aware that our results are limited to the experimental conditions in the laboratory, but they may shed light on how to manage passenger behaviour on platforms with low-cost measures.

Keywords: public transport, passengers, behaviour

1. INTRODUCTION

This work presents the results of a line of research that studies, through real-scale laboratory experiments, how the design of vehicles and platforms affects passenger service time, also called dwell time (Fernández et al, 2010; 2015). The dwell time is the time it takes for a public transport vehicle to get its passengers on and off. Hereinafter, we will refer to "station" to indicate any place to transfer passengers. Also, “vehicle” will mean any public transport vehicle such as a metro train, tram, normal bus or articulated bus. The dwell time affects delays at stations, which, in turn, influence passenger waiting times, their travel times and, in general, the entire public transport system. It also allows public transport operators to calculate their fleet size, vehicle type, driver allocation, vehicle mileage, and operating costs.

The advantage of full-scale laboratory experiments is that we can test passenger behaviour against different designs of vehicles, platforms and flow control which cannot be done in the field or in circumstances that do not occur in reality. For example, how passengers behave in a vehicle with 2.5-m doors.

The objective of this work is to present the results of experiments carried out in the Human Dynamics Laboratory (HDL) of the Universidad de los Andes, Chile. The experiments studied the effect on the boarding and alighting times of managing the flow of passengers in front of the doors. In particular, it was analysed how markings on the platform affects the passengers’ behaviour; specially, that passengers waiting to board do not obstruct those who are alighting. Obstructing the doors is common in rush hour metro systems because vehicles are overcrowded and waiting passengers are anxious to see that they will not be able to board the train. As a consequence, they stand in front of the doors and block the flow of passengers that goes down.

Our methodology consisted of experiments in which the width of the doors and the vertical and horizontal gaps between the platform and the vehicle were kept constant. Five marking schemes on the platform were studied. Students played as passengers in the experiments, so the resulting values are not directly transferable to a real system. Our aim was to compare the trends and relative differences between schemes. Subsequently, the best scheme can be taken to the field to corroborate its effectiveness. Likewise, it is possible to determine which scheme not to use in practice.

2. BIBLIOGRAPHIC REVIEW

The dwell time is the time that a public transport vehicle stands in a station transferring passengers, from its stop until it advances again. There are six main variables that affect dwell time, two belong to passenger demand and the other four relate to boarding and alighting processes (TRB, 2000). These factors are: (a) the number of passengers getting on and off the vehicle; (b) the size and design of the stations; (c) the fare collection method; (d) the type of vehicle; (e) the movement of passengers inside the vehicle; and (f) boarding and alighting of wheelchairs, shopping carts or baby carriages. All these factors change with the design of the stations, characteristics of vehicles, type of passengers and demand levels.

There are an extensive number of models to calculate dwell time, most of them focusing on the bus system. The most relevant ones will be explained below.

Levinson (1983) was one of the first to carry out studies and points out that dwell time is affected by the activity of passengers, which door is used to get on and off, the number of passengers who pay with coins or notes, frequency of stops and time of the day. Meanwhile, Pretty and Russel (1988) proposed the following model.

$$T = C + max\left\{\sum_{i=1}^{m} a_i \,; \sum_{j=1}^{n} b_j\right\} \tag{1}$$

Where T is dwell time; a_i the boarding time of passenger i; b_j is the alighting time of passenger j; n is the number of passengers boarding; m the number of passengers alighting; and C the dead time for opening and closing doors.

Lin and Wilson (1992) state that dwell time is affected by many factors. However, most of these factors are constant, with the exception of passenger demand and behaviour. There are other variables, such as the time the driver waits to close the doors or if any passenger has a disability. These cannot be used to predict system performance, because they are unpredictable. For this reason, their model does not include these factors as variables, but it does include within the prediction error. What it does consider is the number of passengers boarding and alighting and the number of passengers on board the vehicle. Therefore, for the particular case of a one-door vehicle, the time required for boarding and alighting is:

$$DOT = a + bDONS + cDOFFS + d(DONS + DOFF)STD \tag{2}$$

Where DOT is time the door remains open; DONS the number of passengers that board through the door; DOFFS the number of passengers alighting through the same door; STD is the number of people standing in the vehicle; and DT the vehicle stopping time. Finally, a, b, c, d are parameters to be calibrated.

If the vehicle has n doors, then $\mathrm{DT} = \max\{\mathrm{DOT_1}, \mathrm{DOT_2}, \dots, \mathrm{DOT_n}\}$ and, if the vehicle has m carriages, $\mathrm{DT} = \max\{\mathrm{DT_1}, \mathrm{DT_2}, \dots, \mathrm{DT_m}\}$. Parameters were estimated on the Green Line trains of the Massachusetts Bay Transportation Authority (MBTA).

Puong (2000) proposes a model based on data observed in the MBTA Red Line. His study shows that dwell time is a linear function with the number of passengers boarding and alighting and non-linear with the number of passengers on board.

In a comprehensive study in buses of Sydney, Tirachini (2013) calibrated dwell time models. The objective was to quantify the differences between payment methods, age of the passengers, steps to get in the vehicle and friction between passengers who get on and off, and passengers standing inside the vehicle. Equation 3 shows one of his simplest models.

$$d = c + b_e B_e + b_c B_c + b_s B_s + b_t B_t + aA + \varepsilon \tag{3}$$

Where d is dwell time; A is the number of passengers getting off; a is the alighting time per passenger (s/pas); B_k is the number of passengers who pay using the k system (exact fare, giving change, free of charge, daily ticket); b_k are the respective boarding time per passenger (s/pas) and ε is the residual error.

At train stations in the Netherlands, Wiggenraad (2001) observed that dwell time is determined by a fixed stopping time, defined for each station, the number of passengers boarding and alighting, the characteristics of the train and the infrastructure, the processes of arrival and departure of trains, the distribution of passengers at the station and the period of the day. He concludes that the dwell time is greater than the fixed stop time and that the dwell time is similar at peak and off-peak times. He also observed that there is a concentration of passengers around the train's stop place and that the average time for boarding and alighting passengers is approximately one second. Also, wider doors reduce passenger boarding and alighting time by approximately 10%. Conversely, narrower doors increase boarding and alighting time by approximately 10%.

Heinz (2003) measured the boarding and alighting times for different types of trains in Sweden, considering the type of service, the vertical gap between the platform and the train, the width of the doors and the percentage of passengers with luggage. The results are shown in Table 1.

Table 1. Passenger boarding and alighting times in Swedish trains.

Type of service	Vertical gap (m)	Width of doors (m)	Passengers w/luggage	Boarding time (s/pas)	Alighting time (s/pas)
Local	0.03	1.19	0%	1.51	0.88
Local	0.10	1.41	0%	1.38	0.93
Local	0.42	0.77	0%	1.66	1.40
Local	0.42	1.15	0%	1.19	1.11
Regional	0.57	0.90	9%	1.94	1.38
Regional	0.57	0.90	4%	2.96	2.02
Regional	0.57	1.15	11%	1.98	1.22
Regional	0.02	1.15	7%	1.61	1.04
Regional	0.05	1.15	2%	2.26	1.70
Regional	0.39	1.90	8%	1.75	1.22
Regional/Airp	0.00	0.82	14%	1.71	1.42
Regional/Airp	0.44	1.46	57%	1.99	1.56
Regional/Airp	0.02	1.46	56%	1.65	1.59
Regional	0.67	0.60	16%	3.85	2.30
Regional/Inter	0.67	0.75	10%	2.55	2.18
Intercity	0.67	0.74	23%	3.83	3.77
Intercity	0.67	0.63	31%	4.22	4.53
Intercity	0.72	1.30	12%	3.17	2.08

In the previous models, the parameters were calculated through linear regression. In contrast, Daamen et al (2008) studied the behaviour of railway passengers through real-scale laboratory experiments. In the experiments they obtained the capacity of the doors versus changes in vertical and horizontal gaps, door width, and passengers with and without luggage. The results indicate that increasing the vertical and horizontal gap, the capacity of the doors is reduced by up to 15%. On the other hand, if there are passengers with luggage, the capacity of the doors decreased by up to 25%. Table 2 presents the results.

Table 2. Capacity of an 80-cm door (pas/s)

Vertical gap (cm)	Horizontal gap (cm)					
	Passengers without luggage			Passengers with luggage		
	5	15	30	5	15	30
5	0.91		0.85	0.69		0.73
20		0.89	0.88		0.62	0.64
40	0.81		0.77	0.65		0.63
60		0.84	0.77		0.60	0.56

Following this approach, Fernández et al (2010) obtained passenger boarding and alighting times through laboratory experiments carried out at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) of University College London. The scenarios considered different methods of payment, door widths, vertical gaps and passenger density on board the vehicle. Figure 1 shows the effect of passenger density on the boarding and alighting time per passenger.

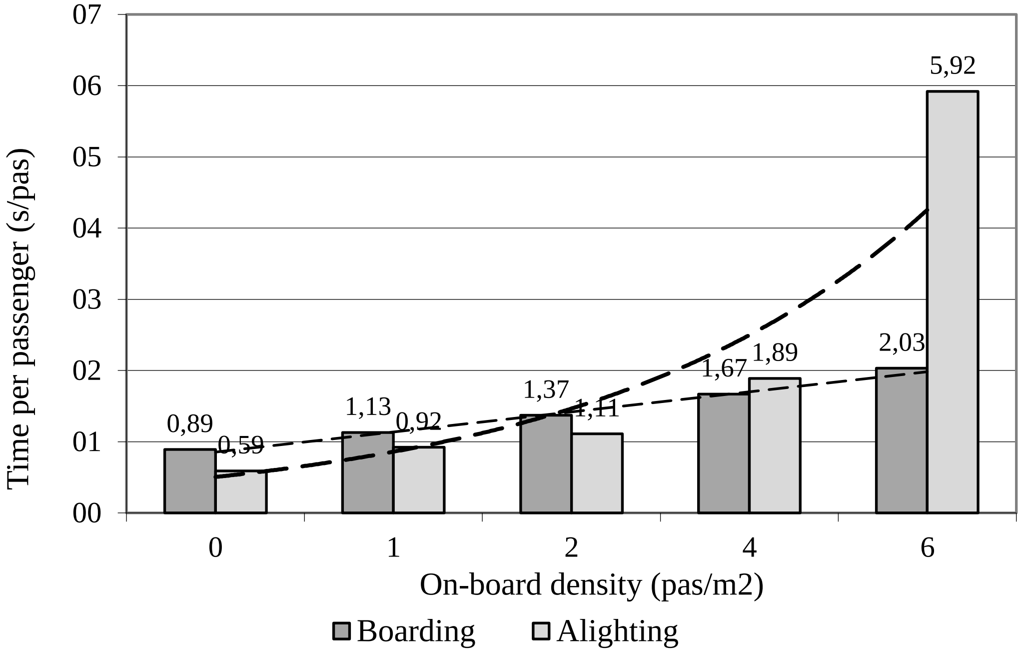

Figure 1. Boarding and alighting times with respect to on-board density of passengers

As can be seen in the figure, there is a linear increase in the boarding time per passenger as a result of density, but on the other hand, the alighting time per passenger tends to increase exponentially. This is explained by the fact that when passengers get on, they push those who are on board; instead, when passengers get off, they must make their way between those who are standing.

Similarly, Fernández et al (2015) measured the discharge capacity of a vehicle door in the Human Dynamics Laboratory (HDL) of the Universidad de los Andes, Chile. Figure 2 shows the results where it is observed that the highest discharge rate is 2.06 pas/s and is reached for a 1.65-m wide door.

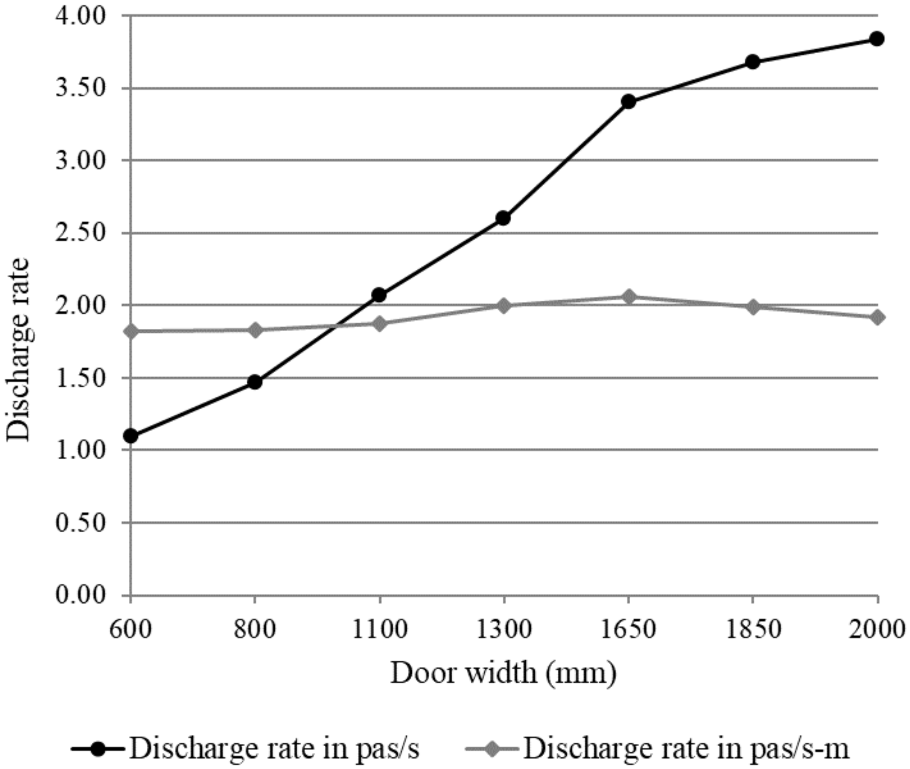

Figure 2. Discharge rate through a public transport door

3. EXPERIMENTS

3.1. Design of experiments

When experiments are carried out, the variables are separated into two types: experimental variables and contextual variables. The experimental ones are those that the researcher will modify to obtain the results of the experiment, in our case, how the markings on the platform influence passenger behaviour. Contextual variables are those that are not modified, but also have influence on the behaviour. In our case, they were 1.65-m doors, null horizontal and vertical gaps, and 4 passengers per square meter inside the mock-up at the beginning of each boarding and/or alighting process.

Thirty simulations of simultaneous boarding and alighting processes were carried out for each marking scheme. Each scheme was studied on different days and about 40 people participated each day. More or less the same people attended the laboratory each day, and between each experiment the participants were asked to mix before each boarding and alighting process. The marking of waiting areas on the platform was made with adhesive tape. Figure 3 shows the floor plan of the HDL.

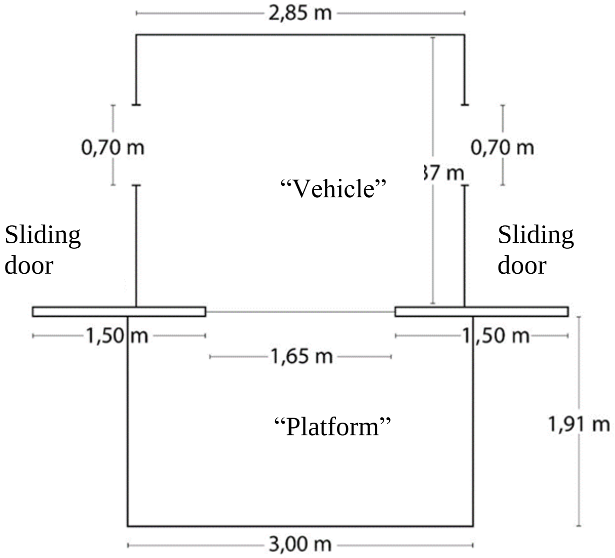

Figure 3. Floor plan of the mock-up at the HDL

To calculate the times of boarding (T_{si}), alighting (T_{bi}) and simultaneous boarding/alighting (T_{sbi}), the following criteria were used. The process begins when half of the body of the first passenger crosses an imaginary line of separation between the vehicle and the platform. The process ends when the half of the body of the last passenger crosses the same line. The doors remain open until the boarding and/or alighting process is complete. Boarding and alighting processes were recorded with a wide-angle GoPro camera located on the door lintel, as well as a front and rear camera, as Figure 4 illustrates.

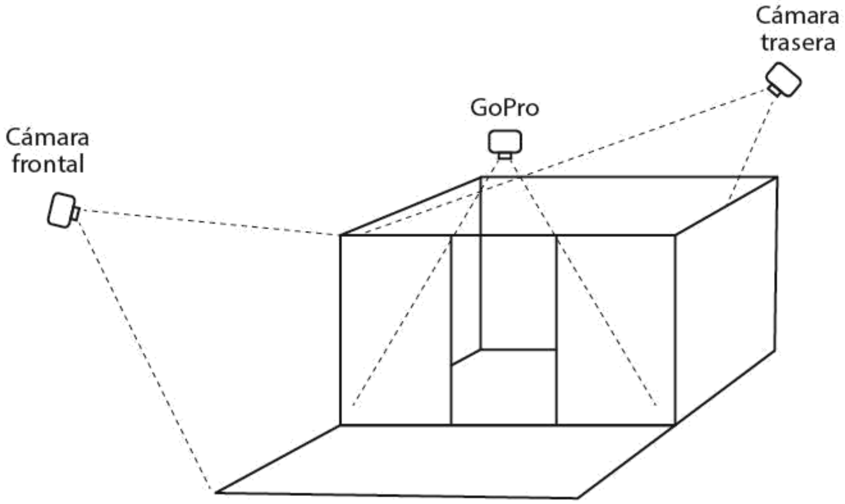

Figure 4. Location of the cameras to record the experiments.

Five schemes were studied. The first, scheme A, is the base case, without any marking. The remaining schemes (B, C, D, and E) are shown in Figure 5.

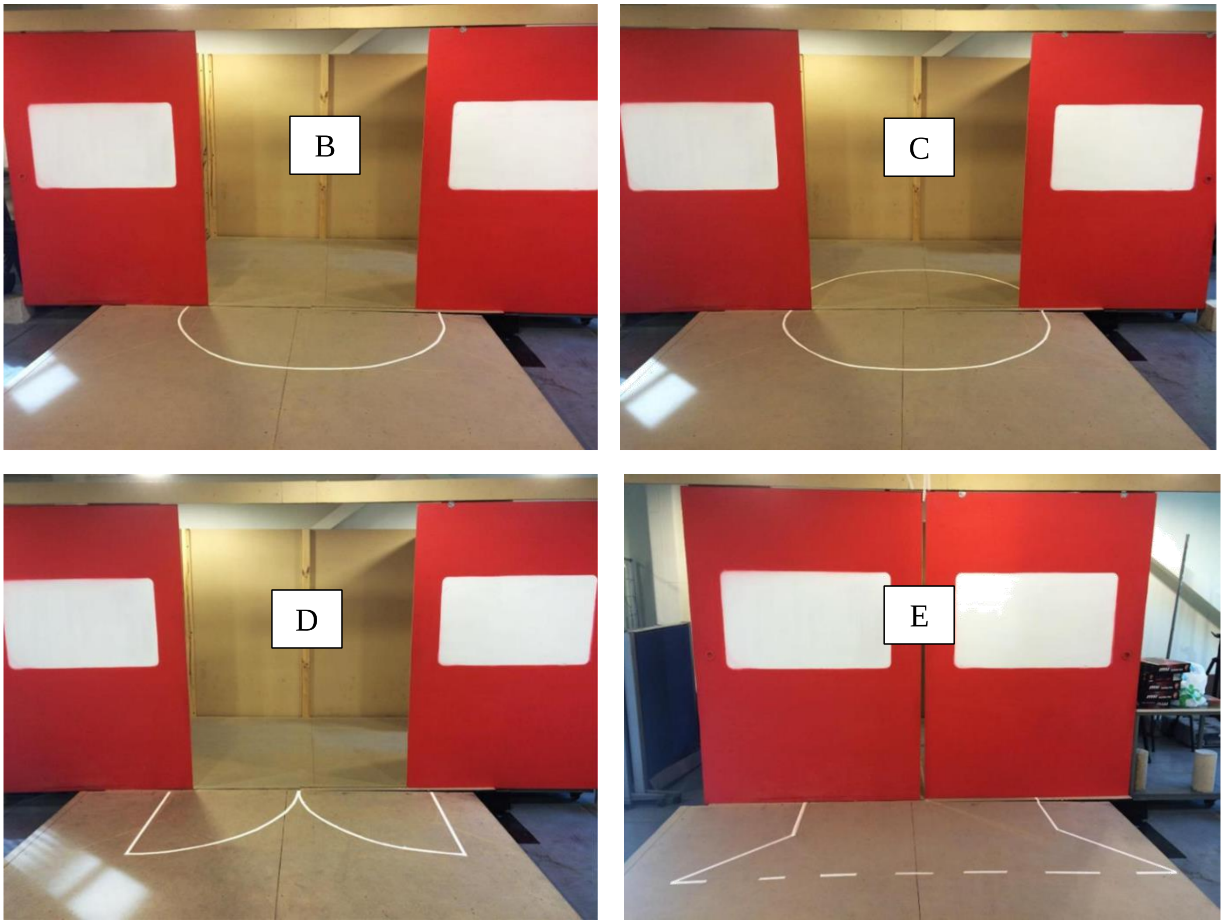

Figure 5. Experimental marking schemes

The calculation of the data was recorded in the form shown in Table 3.

Table 3. Registration and calculation form

Run N°	Boarding pass	Boarding time (s)	Alighting pass	Alighting time (s)	Boarding & alighting pass	Boarding & alighting time (s)	Average boarding time (s/pas)	Average alighting time (s/pas)	Average board & alight time (s/pas)
1									
2									
i	P_{si}	T_{si}	P_{bi}	T_{bi}	P_{sbi}	T_{sbi}	$\beta_{1i}=T_{si}/P_{si}$	$\beta_{2i}=T_{bi}/P_{bi}$	$\beta_{3i}=T_{sbi}/P_{sbi}$
…									
n									
∑	P_s	T_s	P_b	T_b	P_{sb}	T_{sb}	$\beta_1=\Sigma_i\beta_{1i}/n$		$\beta_2=\Sigma_i\beta_{2i}/n$

In the above form, the average boarding and/or alighting times per passenger are denoted by the respective variable β_k.

3.2. Results

According to the calculations in Table 3, the average boarding and alighting times shown in Table 4 were obtained.

Table 4. Average boarding and/or alighting times

Scheme	P_s (pas)	T_s (s)	β_1 (s/pas)	P_b (pas)	T_b (s)	β_2 (s/pas)	P_{sb} (pas)	T_{sb} (s)	β_3 (s/pas)
A	17	11.0	0.64	15	11.0	0.74	32	17.3	0.54
B	27	14.4	0.54	16	8.4	0.52	43	22.6	0.53
C	24	14.0	0.59	16	9.7	0.60	40	22.0	0.55
D	25	15.1	0.61	15	11.0	0.71	40	23.1	0.58
E	27	13.0	0.48	16	7,3	0.46	43	21.2	0.49

The average times have a coefficient of variation – the ratio of the standard deviation to the mean – between 2% and 5%; that is, the experimental results are appropriate for all practical purposes.

In the base case (A) the number of volunteers were not enough to satisfy the density within the wagon. For this reason, the internal area was reduced so that the density of passengers was the established one (4 pax/m^2).

It can be seen from Table 4 that in all schemes the average boarding or alighting times are less than the base case (scheme A), except in two cases of simultaneous boarding and alighting. This is explained in the next Section.

Regarding the comparison between the marking schemes B, C, D and E, the one that produces the least average time is scheme E, that is, a cup-shaped marking. The second optimum is the semicircular scheme B. On the contrary, scheme D, "butterfly", is the least effective. Figure 6 graphically shows the results and Table 5 presents the percentage differences between schemes.

Table 5. Differences without and with markings on the platform

Comparison	Difference with respect to scheme A (%)		
	β_1	β_2	β_3
A-B	-15	-29	-2
A-C	-8	-19	-2
A-D	-5	-4	+7
A-E	-25	-38	-9

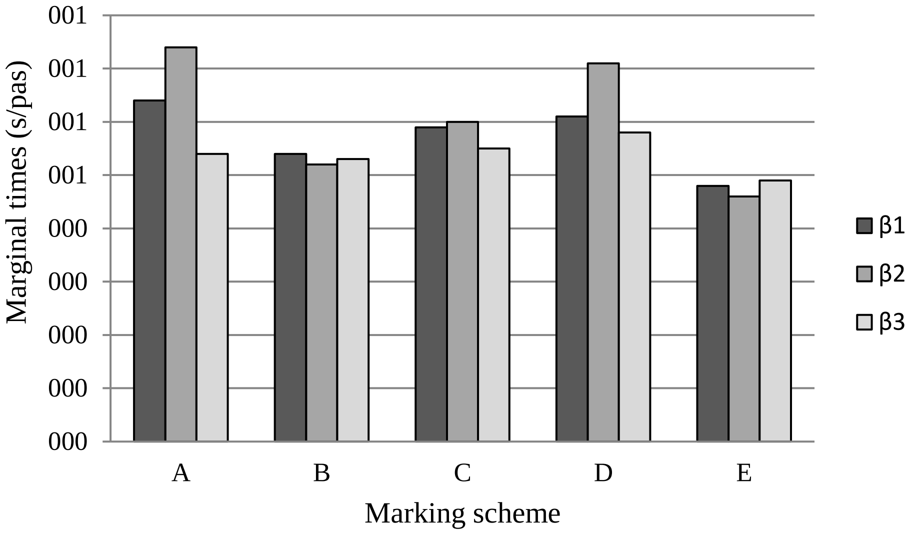

Figure 6. Comparison between marking schemes

3.3. Statistical analysis

To determine if the average times of each scheme with respect to the case without marking (A) are statistically different, the Student's t-test of difference of means for 95%-significance level was applied. The null hypothesis H_0 means that the difference between average times with respect to case A is not statistically significant. The calculations were made using the EasyFit software (MathWave, 2019) and the conclusions regarding the experimental results are presented in Table 6. It is noted that where it says "Accept H_0" means that the test failed to reject the null hypothesis.

Table 6. Statistical analysis of average times

Comparison	Conclusions		
	β_1	β_2	β_3
A-B	Reject H_0	Reject H_0	Accept H_0
A-C	Reject H_0	Accept H_0	Accept H_0
A-D	Accept H_0	Accept H_0	Reject H_0
A-E	Reject H_0	Reject H_0	Reject H_0

A = without markings; B = semicircle; C = butterfly; D = circle; E = cup

It can be seen from the table that in the case of the average boarding time (β_1) it is not possible to establish that scheme D differs from A. In contrast, in all the other schemes the values of β_1 are statistically different from A. For the average alighting time (β_2) it was not possible to verify that the schemes C and D are better than A, but markings B and E manage to reduce β_2. And for the average boarding and alighting time (β_3) it is shown that schemes D and E are statistically different from A. However, scheme D produces a significant increase of 7% with respect to scheme A. This suggests that a butterfly-type marking is not recommended.

In summary, the results are diverse, but it is clear that the cup-type scheme (E), reduces between 9% and 38% the average boarding and/or alighting times with respect to not using markings on the platform. It is also highlighted that scheme B reduces by 15% to 29% the average boarding (β_1) and alighting (β_2) times, but it has no effect on β3.

Making some assumptions and using the values of β_1 and β_2 from Table 6, the following comparison can be made between scheme A and scheme E. A BRT system of 10 km and 20 stations would decrease the total delay in stations by 13% (from 11.3 min to 9.8 min) and would reduce the total travel time by 6% (from 23.2 min to 21.8 min). Consequently, the commercial speed would increase from 26 to 28 km/h. Although the percentages seem lower, considering the passenger demand, the number of hours per year and the value of users' travel time, the benefit will offset the investment in markings.

4. CONCLUSIONS

In this article we have presented the effect of different marking schemes on the platform on the passengers' behaviour to reduce the average boarding and alighting times in public transport vehicles. The methodology consisted of real-scale experiments carried out in the Human Dynamics Laboratory of the Universidad de los Andes, Chile in a mock-up of a public transport vehicle. The results indicate that a cup-type marking is the most effective to reduce average times. In addition, a semicircle marking reduces the de boarding or the alighting time, but not the simultaneous boarding and alighting times.

Laboratory experimentation as a research method provides an opportunity to study cases in which one variable is controlled, while the rest remain constant. The advantage of this approach in our case was that we can test the behaviour of passengers under different flow control conditions. Thus, it was possible to test new platforms marking scenarios in front of the doors of a public transport vehicle.

We recognize that the limitations of the methodology are at least two. First, the experiments were performed in a modest full-scale laboratory, so the conclusions are limited to this installation. Second, the subjects who participated in the experiments were students; that is, homogeneous people in terms of physical conditions. However, what was wanted in this study was to calculate the relative - rather than absolute - differences between marking schemes on platforms. This allow us to establish what is the best scheme as well as the least efficient.

Future research using this experimental approach are, among others, testing the behaviour of heterogeneous subjects, such as people of different ages, sex and mobility conditions, as well as studying the impact of passenger density on the platform and on board the vehicle.

Finally, it would be in the interest for public transport operators to carry out pilot experiences to validate our experimental results, in particular the percentages of reduction in station delays and travel times. This was not possible in this study because, under the Covid-19 conditions, public transport demand reduced dramatically, and field studies could not be performed because of restrictions imposed by the public transport authorities.

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