PLATFORM HEIGHT, DOOR WIDTH AND FARE COLLECTION ON PUBLIC TRANSPORT DWELL TIME: A LABORATORY STUDY

Rodrigo Fernández, Universidad de los Andes, Chile

Pablo Zegers, Universidad de los Andes, Chile

Gustavo Weber, Universidad de los Andes, Chile

Álvaro Figueroa, Universidad de los Andes, Chile

Nick Tyler, University College London, UK

INTRODUCTION

Public transport vehicles spend a substantial amount of their journey time stationary at stops for boarding and alighting passengers. As an illustration, let us consider a bus lane of one kilometre long. Suppose that 30 buses per hour run on that lane and they stop at three bus stops along the bus lane taking 30 seconds for boarding and alighting passengers at each stop. Besides, suppose that there are eight traffic signals in the one-km section, each of them working with a 60 second cycle time and 30 second green time for the bus lane. Under these circumstances, the average delay at traffic signals will be 8 seconds per bus. If the running speed of buses is 54 km/h, they will spend in total 67 seconds in movement, 64 at traffic signals, and 90 seconds at bus stops. In other worlds, the journey time of buses will be made of 30% in movement, 29% delayed at junctions and 41% stationary at bus stops. Despite that this is an arbitrary example the result is of general validity: buses spend about 40 to 50% of their journey time at bus stops. More cases can be found in TRB (2003). Therefore, the calculation of dwell time at stops should be of interest to transport planners and modellers if they want to provide accurate predictions of public transport travel times.

The dwell time is the time that a public transport vehicle remains stopped transferring passengers. It depends on the number of boarding and alighting passengers, plus other operational characteristics such as the fare collection method, number of doors and steps, internal layout of vehicles, etc. Traditionally, the dwell time has been described as a linear function of the number of passengers boarding and alighting. We have been studied the dwell time of buses in Santiago de Chile since 1995 (Fernandez et al, 1995). In the case of two-door buses we have found that the dwell time depends also on the vehicle occupancy, congestion on the platform, and number of passengers stored before the fare collection point inside the bus. Parameters represent the boarding and alighting time per passenger and other lost times spent at stops, such as the time for opening and closing doors and the time taken for passenger to walk from their standing point to the stopped bus.

This article shows a research to obtain parameters of the dwell time model for different physical configurations of buses from laboratory experiments. These parameters can then be used to perform computational simulations to observe their importance on public transport operations. Experiments were performed at the Pedestrian Accessibility and Movement Environment LAboratory (PAMELA) of University College London with semiautomatic and artificial vision methods. Our hypothesis is that operational features such as platform height, door width, and fare collection method are relevant on the dwell time, and the controlled study in laboratory of these variables will allow us to observe its relative importance. In these experiments, only the most important parameters of the dwell time were studied: average boarding and alighting times per passenger, also called marginal boarding and alighting times. The collection method was video recordings of boarding and alighting operations on a stationary mock up of a bus. Video tapes were then processed by means of two methods: visual observation and ViPER-GT (Video Performance Evaluation Resource Ground Truth). ViPER-GT allows the experimenter to relate some event in the image with an automatic record of the event, such as its time. In this way, it was possible to define the time that each passenger takes crossing the door frame of the vehicle. The average of these times made the average boarding and alighting times.

This paper describes first some models of dwell time reported in the literature. We briefly reported the American experience, but also we dedicate space to explain the British and Chilean experience. Next, the way in which experiments were performed and data collected is explained. Then, results of the parameters of dwell times are presented and discussed. After that, the way in which we are applied computational vision techniques to the data collection task is described. Finally, some comments on the whole work are stated.

DWELL TIME MODELS

Traditionally, the dwell time has been described as a linear function of the number of boarding and alighting passengers, affected by certain parameters that represent the speed of entry and exit, plus any dead time (opening and closing doors, walking to the stopped vehicle, etc.). Several functional forms have been suggested. In the following, a summary made by Fernandez et al (2010) is reproduced and updated.

American literature on dwell time models is abundant. It is not our objective to make a thorough review of it. Just to mention a few contributions, Lin and Wilson (1992) studied the dwell time for LRT systems. They found that, in addition to boarding and alighting passengers, dwell times are also affected by the number of passengers on board the vehicles, improving the explanatory power of the prediction. They also tested nonlinear functions and found that these perform better that linear ones. After that, Aashtiani and Iravani (2002) proposed several nonlinear dwell time models including the load factor of the vehicles and the number of doors. Rajbhandari et al (2003) tested various linear and nonlinear regression models from automatic passenger counts. They reported that additional variables such a as the number of doors of vehicles and the fare collection method will increase the explanation of bus dwell time. The work of Li et al (2006) on the other hand presents an interesting method to estimate the door choice for alighting passengers. In Jaiswal et al (2009) it was stated that platform crowding is one of the explanatory variables of dwell time in busway stations. According to these authors, there is virtually no literature in which this variable is found to be relevant in bus dwell time. Finally, in the work of Daamen et al (2008) real-scale experiments were performed to study the behaviour affecting dwell time in Dutch trains; in particular, the effect of the vertical and horizontal gap between the train and the platform in addition with the amount of luggage.

Another well-known American model is the Highway Capacity Manual (HCM) formula (TRB, 2000) for the dwell time:

$$t_d = P_a t_a + P_b t_b + t_{oc} \tag{1}$$

Where t_d is the dwell time in the bus stop; P_a and P_b are the numbers of alighting and boarding passengers per vehicle through the busiest door; t_a and t_b are the average alighting and boarding time per passengers respectively; and t_{oc} is a dead time for opening and closing doors. The Transit Capacity and Quality of Service Manual – TCQSM – (TRB, 2003) states ranges of values for t_a, and t_b for different conditions. These values are shown in the following table.

Table 1 *– Parameters of dwell time from the TCQSM [s/pass]*

Situation	Observed Range	Suggested Value
Boarding		
Pre-payment	2.25 – 2.75	2.5
Single ticket	3.4 – 3.6	3.5
Exact change	3.6 – 4.3	4.0
Swipe or dip card	4.2	4.2
Smart card	3.0 – 3.7	3.5
Alighting		
Front door	2.6 – 3.7	3.3
Rear door	1.4 – 2.7	2.1

In the European experience the work of Pretty and Russel (1988) must be mentioned. They proposed the following dwell time model.

$$T = C + \max\left\{\sum_{i=1}^{m} a_i ; \sum_{j=1}^{n} b_j\right\} \tag{2}$$

Where T is the stopped time measured since the wheels of the bus are stopped until they start to move again; a_i and b_j are the time that each passenger takes for alighting and boarding, respectively; n and m are respectively the number of alighting and boarding passengers; and C is the dead time for opening and closing doors. If we assume that each passenger takes the same time boarding or alighting, then the above equation becomes:

$$T = C + \max\{mA; nB\} \tag{3}$$

Where A and B are the average alighting and boarding time per passenger respectively. Following this line of thinking, York (1993) updates previous studies from Cundill and Watts (1973), where different values for the average boarding time were observed as a consequence of the payment method. Following these, York proposes the following functional specifications.

For one-door buses:

$$T = D_0 + Aa + \sum_{i=1}^{m} B_i b_i \tag{4}$$

For two-door buses:

$$T = \max\left\{D_a + Aa; D_b + \sum_{i=1}^{m} B_i b_i\right\} \tag{5}$$

Where T and A have the same explanation as above; a is the number of alighting passengers. Parameters B_i are average boarding times for the payment method i (travel card, exact fare, change given); b_i is the number of boarding passenger using the payment method i; and m is the number of payment methods. D_j is the dead time for alighting (j = a), boarding (j =b), or alighting and boarding (j = 0). In summary, rages of values for the parameters found by York (12) for London buses are:

- Dead time: 2.8 to 8.3 seconds
- Boarding time: 1.6 to 8.4 seconds per passenger
- Alighting time: 1.1 to 2.0 seconds per passenger

In Chile, an extension of the previous models was developed by Fernandez et al (1995) and Gibson et al (1997) for conventional high-floor 10-m 2-door buses in Santiago. It was found that the dwell time depends on the following characteristics:

- the existence of a well-defined platform at the bus stop;
- how congested the platform is;
- the occupancy of buses; and
- the amount of passengers that can be stored before the fare collection point.

The resulting model is show in the following equation.

$$DT = \left(\beta_0 + \beta_o^{'}\delta_1\right) + \max_{j=door}\left\{\left(\beta_1 + \beta_1^{'}\delta_1 + \beta_1^{''}\delta_2\right)P_{bj} + \left(\beta_2\, e^{-\beta_2^{'}PA_j} + \beta_2^{''}\delta_3\right)P_{aj}\right\} \tag{6}$$

In the above model, DT is the dwell time, P_{bj} and P_{aj} are the number of boarding and alighting passengers through door j, respectively; β^i_k are parameters so that β^i_0 are dead times, β^i_1 are boarding times per passengers and β^i_2 are alighting times per passenger (except β'_2 which is the parameter of the exponential function). Variables δ_k are dummy variables so that δ_1 =1 if there is congestion on the platform, δ_2 = 1 if more than four passengers board the bus and δ_3 = 1 if the aisle of the bus is full; otherwise, they are zero. Parameters of this dwell time model calibrated in Santiago are show in Table 2.

***Table 2** – Parameters of the dwell time in Santiago de Chile*

Parameter / **Stop Type**	β_0 [s]	β'_0 [s]	β_1 [s/pas]	β'_1 [s/pas]	β''_1 [s/pas]	β_2 [s/pas]	β'_2 [pas]$^{-1}$	β''_2 [s/pas]
Formal	0	2.34	2.99	0.40	0.43	2.00	0.035	1.14
Informal	1.17	0	3.48	0.34	0.78	1.44	0	0.76

The values of the parameters can be explained because of the rather informal operational condition at that time. Firstly, few bus stops had well-defined platforms; the vast majority was just a pole on the pavement. Second, a low dead time is observed because buses stop and start their movement with the doors opened. Third, the average boarding time of about 3 to 4 seconds per passengers was mainly due to the ticketing system: a flat fare paid in cash to the driver given change. The increase on the average boarding time between 0.43 to 0.78 seconds per passenger for more than four passengers boarding was due to the storage capacity between the first step of the bus and the fare collector (the driver). Because of the width of the aisle, if this was full of passengers, the average alighting time increases 0.76 to 1.14 seconds per passenger. For the same reason, if many passengers alight the process speeds up because a sort of transient queue discharge mechanism takes place in the aisle. The speeding effect takes the form of a negative exponential value of the average alighting time. This was only observed at formal platforms where bus with more demand stop.

As a way of illustration, in a formal bus stop if the platform is congested, the above model predicts a dead time of 2.34 seconds, and the boarding time will be 0.4 seconds higher (13%) than the case when there is no congestion on the platform. In addition, if more than 4 passengers board a bus, the boarding time will increase another 14% (0.43 seconds). On the other hand if 10 passengers alight from the bus, the alighting time will be reduced by 16% compare with the case in which only 5 passenger get off the bus; however, if the aisle is full, the alighting time can increase by 57%.

On February 2007 a new bus network came into operation in Santiago de Chile, called Transantiago. This consisted on truck routes served by both low-flow 18-m articulated buses with four door and low-floor 13-m rigid body buses with three doors. The feeder routes are served with high-floor midi buses with 2 doors and part of the old 10-m 2-door buses. The fare in not longer collected by drivers, but by means of a card which is electronically read either inside the vehicle or in the platform at the busiest bus stops.

The change in the structure of the network and in the type of vehicles made obsolete the dwell time model show in Equation (6). As a result a field study campaign was preformed in trunk and feeder bus stops (Del Campo, 2009; Lira, 2009) as well as in metro stations (Swett, 2008). This study was funded by the National Fund for Science and Technology of the Chilean Government (FONDECYT for its name in Spanish). Its objective was the specification of new dwell time models for the current operational conditions in both bus and metro systems.

Results obtained at metro stations are summarised in Table 3, where t_{ab} is the breaking and accelerating time at the station. It is made of two components. The first component is the time since the front of the train appears in the mouth of the tunnel until the trains has completely stopped. The second component is the time since the train starts its movement until the back of the train disappears in the tunnel. Parameters β_0, β_1, and β_2 are respectively the dead time per stop, the average boarding time, and the average alighting time per passenger.

Table 3 *– Parameters of dwell time for Metro de Santiago (Swett, 2008)*

Parameter	Mean Value	Standard Deviation
t_{ab} [s]	22.40	0.83
β_0 [s]	3.24	0.91
β_1 [s/pass]	1.13	0.53
β_2 [s/pass]	0.70	0.26

We could not calibrate a dwell time model because we could not get authorisation by Metro de Santiago to collect data in the peak period due to the overcrowding at stations. However we do could take videos during off-peak periods focused the camera on the doors of one carriage of each train. These videos were then processed with the software ViPER-GT (Doermann and Mihalcik, 2000). Thus, we measured the entry and exit time of each passenger. During off-peak periods the dwell time of metro trains is not govern by the number of boarding and alighting passengers, but by traffic control and safety regulations. Then, we assumed for the metro that the dwell time model is linear as follows in which all variables have been defined before.

$$DT = \beta_0 + \max_{j=door}\{\beta_1 P_{bj} + \beta_2 P_{aj}\} \tag{7}$$

Vuchic (2005) states that in metro systems both the boarding and alighting times are about one second per passenger. The results found in this study come to confirm this magnitude as well as the fact that the average alighting time is 40% lower than the average boarding time.

In the case of buses, the new operational characteristics make that some of the explanatory variables of the dwell time model of Equation (6) are not longer valid. Firstly, buses stop only at formal bus stops and, as a result, platforms present some degree of congestion. Second, the new ticketing system (electronic cards without physical contact) makes the boarding process easier, so the size of the hall of vehicles is less important than before. However, it is still important whether the aisle of the bus is full of passengers or not. According to the above conditions, new functional specifications and parameters were obtained by Lira (2009). This work provided different models for trunk and feeder services as well as for on-board payment and pre-payment. A summary it is summarised in the following equations.

1. Trunk route, pre-payment: $$DT = \beta_0 + \max_{j=door}\left[\left(\beta_1 + \beta_1^{'}\delta_1 + \beta_1^{''}\delta_2\right)P_{bj};\beta_2 P_{aj}\right] \quad (8)$$

2. Trunk route, on-board payment: $$DT = \beta_0 + \max_{j=door}\left[\left(\beta_1 + \beta_1^{''}\delta_2\right)P_{bj};\beta_2 P_{aj}\right] \quad (9)$$

3. Feeder route, pre-payment: $$DT = \beta_0 + \max_{j=door}\left[\left(\beta_1 + \beta_1^{'}\delta_1\right)P_{bj};\beta_2 P_{aj}\right] \quad (10)$$

4. Feeder route, on-board payment: $$DT = \beta_0 + \max_{j=door}\left[\beta_1 P_{bj};\beta_2 P_{aj}\right] \quad (11)$$

Where β^i_k, P_{bj} and P_{aj} have the same meaning that in Equation (6) above; δ_1 and δ_2 are dummy variables where δ_1 = 1 if the platform is congested and δ_2 = 1 if the bus is crowded, otherwise they are set to zero. It was considered that a bus is crowded if all seats are taken and standees occupy more that half of aisle. The platform was considered congested if waiting passengers could not board the bus.

Values of parameters are presented in the following tables for trunk and feeder routes. In the tables, the measured parameters are the average observed value over all passengers and buses, whereas calibrated parameters where obtained by regression. The range in boarding times considers as minimum value all the respective dummy variables set to zero and as maximum value all equal 1.

Table 4 *– Parameters of dwell time model for Transantiago buses in trunk routes*

Parameter	Measured	Calibrated	t-statistic
Pre-payment			
Dead time [s]	5.77	4.74	2.45
Boarding time [s/pass]	1.74	1.75 – 2.15	10.88
Alighting time [s/pass]	1.26	1.29	2.74
R^2	–	0.72	–
On-board payment			
Dead time [s]	7.06	11.47	5.66
Boarding time [s/pass]	1.55	1.08 – 1.71	4.30
Alighting time [s/pass]	0.99	0.98	5.08
R^2	–	0.70	–

***Table 5** – Parameters of dwell time model for Transantiago buses in feeder routes*

Parameter	Measured	Calibrated	t-statistic
Pre-payment			
Dead time [s]	3.96	3.01	1.83
Boarding time [s/pass]	2.08	2.09 – 2.29	19.56
Alighting time [s/pass]	1.68	1.39	2.55
R^2	–	0.94	–
On-board payment			
Dead time [s]	6.19	4.71	2.4
Boarding time [s/pass]	2.13	2.65	18.31
Alighting time [s/pass]	1.43	1.71	6.44
R^2	–	0.85	–

Results indicate that calibrated parameters of the new dwell time model for Santiago seem appropriate compared with the observed values. Similarly to the previous system in trunk routes the boarding time per passenger increases as the bus is crowded, probably because most passengers make use of those services. In addition, at pre-payment stops – both trunk and feeder – the effect of platform congestion is apparent. This is explained because at pre-payment stops passengers can board though any door, so they do not queue; instead, they wait in groups in front of bus doors.

Boarding times have decreased compared with those of the former bus system. However, in feeder services changes are less pronounced, mainly because feeder buses are similar to older buses: smaller than trunk buses, with narrow doors and many steps. Alighting times on the other hand remained almost unchanged.

It should be noted however, that there was a marked increase in dead times for all type of services. In the former bus system the dead time was almost negligible, if any (1 to 2 seconds), but now it rises up to 7.1 seconds. A possible explanation is that now buses open their door when they are completely stopped and start moving when doors are closed. In any case, dead time values are close to the maximum value observed by York (1993) in London buses (about 8 seconds).

LABORATORY EXPERIMENTS

As a way to complement the models calibrated by mean of field studies for Transantiago, a set of experiments were performed in the Pedestrian Accessibility and Movement Environment LAboratory (PAMELA) of University College London during October 2008 and October 2009. PAMELA is a reconfigurable laboratory that is able to simulate existing and proposed pedestrian environments (www2.cege.ucl.ac.uk/pamela). In this laboratory a mock up of a bus was set up (Figure 1).

***Figure 1** – Mock up of a bus in PAMELA.*

To simulate the boarding and alighting processes, wooden blocks were used to represent a typical Transantiago bus as show in Figure 2, where all measures are in millimetres. The layout represents a left-hand drive bus because British people were used in the experiments. In Figure 2 the boarding part of the mock up is shown with a dashed line and the alighting one with a dot and dash line.

Experiments took place during three days in which three variables were studied: the vertical gap between the platform and the bus floor, the door width of the bus, and the fare collection system. Three floor heights were tested: 0, 150 and 300 mm; two door widths were checked: 800 and 1,600 mm; and two fare collection methods were investigated: prepaid fare outside the vehicle and on-board payment with an electronic card without physical contact with the card reader. This was simulated asking the people to press a button and wait for a green light to turn on before they go on.

Twenty five people were used for boarding experiments and fifty for the alighting ones. Subjects were taken from the community and they were paid for their participation (PAMELA uses neither students nor voluntary people to avoid experimental bias). They include adults, youngsters, pensioners, men and women. All of them were taken in a random way and they changed between runs and days of the experiments, in the same way as bus passenger vary randomly at bus stops. It would be argued that cultural differences (e.g., people's behaviour, overcrowding tolerance, etc) might create differences in the results between the British test subjects and Chilean bus riders in Santiago. This is an interesting issue, but we were unable to perform experimental test of this type. However, during the 2009 experiments inside densities were tested and up to 8 British passengers per square meter accepted to be accommodated inside the bus. This is about the same the density observed in Chilean buses during the rush hour. Furthermore, videos showed that under overcrowding conditions people's behaviour was similar to that observed in Chile; for example, people pushing to reach an empty space inside the vehicle.

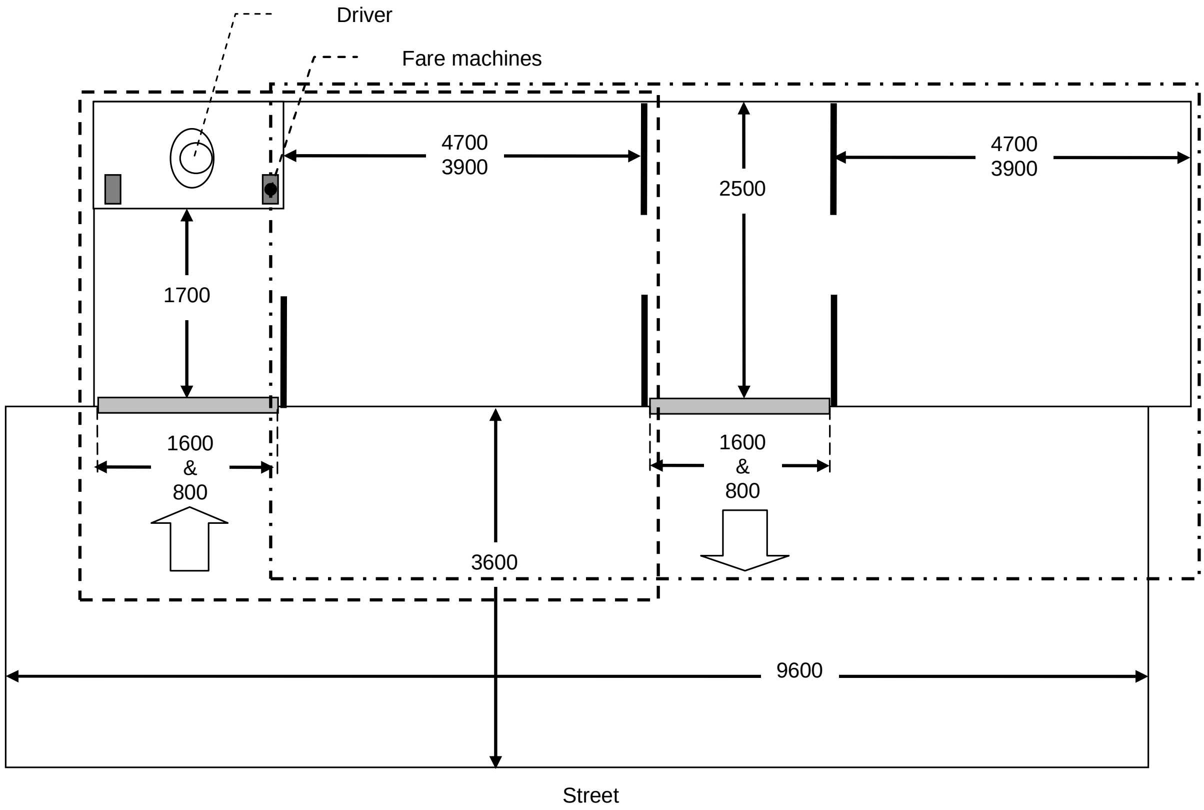

***Figure 2** – Internal and external layout for experiments in PAMELA.*

All the above characteristics are related to Transantiago buses. They use platforms at 300 mm from the road level. Thus, 0-mm vertical gap means a bus stop platform at the same level of the bus floor, 150-mm vertical gap represents a bus stop which platform is at the pavement level, and 300-mm vertical gap is the case when passengers must board from the road level because the bus cannot reach the platform. Most Transantiago buses are new ones with wide doors; others belong to the old fleet with narrow doors. In most cases doors operates one-way. Within the system there are two fare collection methods: on-board payment with an electronic card at normal bus stops and pre-payment on the platform in the case of high-demand bus stops.

In order to get average boarding and alighting time per passenger their activities were recorded with synchronized video cameras of the laboratory from four points of view (Figure 3). The videos were processed in two ways: visual processing and by using the software ViPER-GT showed in Figure 4. ViPER-GT allows the analyst to relate some event on an image with an automatic annotation about that event, such as the time of the event. Thus, it is possible to define the exact time in which a passenger crosses the frame door of the bus.

Figure 3 *– Video recording of PAMELA experiments*

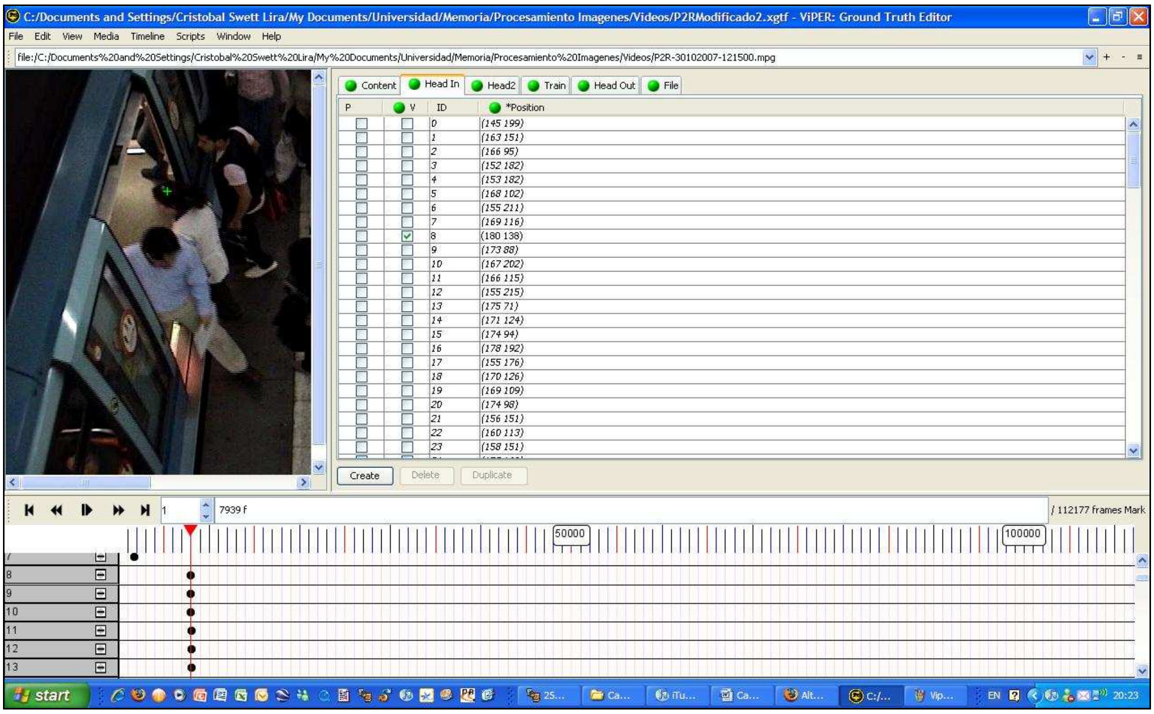

Figure 4 *– Video processing with ViPER-GT.*

During the October 2008 experiments, a relatively free movement of passengers was simulated as there were no obstructions inside the vehicle. However, in October 2009 new experiments took place in PAMELA considering the crowding effect inside the bus. In this case the layout will consider the location of seats and aisle and different passenger densities (from one to six passengers per square meter).

The video processing required precise measurements of the movements of large numbers of people. This involved considerable human resources and showed the difficulty of making statistically valid experiments without more powerful measurement procedures. This fact had an unexpected experimental outcome: an artificial vision system was used to evaluate its feasibility for detecting passengers. Machine learning techniques used to solve these artificial vision problems require a great number of examples (Torralba et al, 2008). Therefore, a medium-size database of passengers and non-passengers examples was built, all of them extracted from the videos taken during the experiments. In order to do that, thousands of pedestrian heads were hand-marked as positive examples to be used in the training of an artificial vision system. Once all the heads on an image were marked by hand, the remaining sections of the image were automatically considered as non-passengers and used as such by the artificial vision training algorithms. Results obtained from these artificial vision techniques are presented in the next section.

EXPERIMENTAL RESULTS

Figure 5 and Table 5 show values of average boarding and alighting times obtained from the PAMELA experiments. The key of physical characteristics “VG000-DW0800” indicates the combination of a vertical gap (VG) between the platform and the bus floor of 0 mm and a door width (DW) of the bus of 800 mm. The text “pay on-board” means that the fare is paid inside the vehicle by an electronic card and “pre payment” means that the fare is collected on the platform outside the bus.

As can be seen in the figure, the best physical configuration for boarding and alighting is a 150-mm vertical gap and a door width of 1,600 mm. This is a rather unexpected result, because engineers have also thought that the best design is to have the platform at the same level of the bus floor. However, it appears that there is a vertical gap which is advantageous for the boarding and alighting speed. This would be the case of bus stop platforms at the pavement level. It seems that the need of a small jump for boarding or alighting speeds up the process.

It is also observed a reduction in the boarding time if the fare is collected outside the vehicle, despite the quick electronic payment method. The differences, however, depend on the door width. For narrow doors (800 mm) the difference ranges from -1 to -8% whereas for 1,600-mm doors the difference increases up to -10 to -22%. This means that it is better to have prepaid stops for buses with wider doors, which is just the case of the Transantiago system.

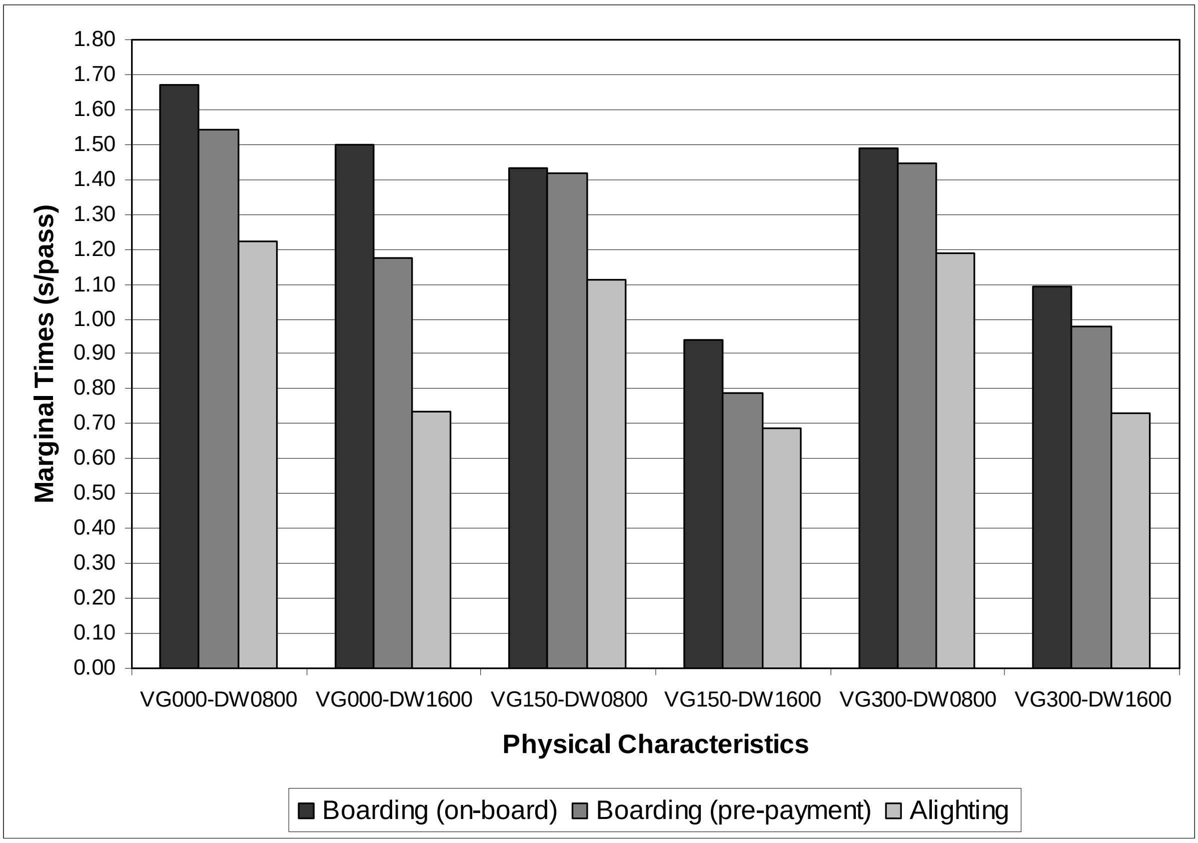

Figure 5 *– Average boarding and alighting times from PAMELA experiments.*

As can be seen in the table, irrespective of the platform height, wide-doors reduce the alighting time by 40%, whereas for the boarding process the boarding time is reduced by 10-34% (on-board payment) and 24-44% (pre-payment). On the other hand, for the same door width the effect of a 0-mm vertical gap only reduces the average alighting time by 9% in the best case. Therefore, it seems that the door width is a more important physical characteristic than the platform height for speeding the boarding and alighting processes.

Table 5 *– Average boarding and alighting times from PAMELA experiments [s/pass]*

Physical Characteristics	Average Boarding Time (pay on-board)	Average Boarding Time (pre-payment)	Difference wrt Pay On-board	Average Alighting Time
VG000-DW0800	1.67	1.54	-8%	1.22
VG000-DW1600	1.50	1.18	-22%	0.73
Diff wrt DW0800	**-10%**	**-24%**	**–**	**-40%**
VG150-DW0800	1.43	1.42	-1%	1.11
VG150-DW1600	0.94	0.79	-16%	0.69
Diff wrt DW0800	**-34%**	**-44%**	**–**	**-38%**
VG300-DW0800	1.49	1.45	-3%	1.19
VG300-DW1600	1.09	0.98	-10%	0.73
Diff wrt DW0800	**-27%**	**-32%**	**–**	**-39%**

In summary, for practical purposes we may recommend the following average boarding and alighting times, irrespective of the platform height.

Table 6 *– Recommended marginal times according to PAMELA experiments [s/pass]*

Door Width	Average Boarding Time		Average Alighting Time
	Pay On-board	Pre-payment	
Wide Doors	1.0 – 1.5	0.8 – 1.2	0.7
Narrow Doors	1.4 – 1.7	1.4 – 1.5	1.1 – 1.2

Finally, on the development of an artificial vision technique, the first step was to establish a reference against which other experiments could be compared. We first chose a learning system based on the Viola-Jones face recognizer (Viola and Jones, 2001), a standard in the artificial vision field. When the trained system was applied to a test set not used in the training stage it only found out 10 heads of the 255 (in other words it missed 245), and it produced 241 false positives; i.e., recognised something else as a human head. An example of this can be seen in Figure 6 (left). This low performance is explained by the fact that this recogniser was designed to work on faces, not heads.

Given the performance of the Viola-Jones method, it was clear that an algorithm focused on the specific problem was needed. In order to establish a reference, a multilayer perceptron (a sort of neural network) was tested (Haykin, 2009). When applied to a test set, also not used in the training process, it found out 664 heads of the 1144 existing in the database and it produced 261 false positives. In other words, it got 58% precision and 23% error. An example of the results produced by our system can be seen in Figure 6 (right). These results are considerably better than those obtained with the Viola-Jones. This is very interesting given the inherent simplicity of the multilayer perceptron technique when compared with Viola-Jones. These results show the feasibility of using artificial vision in future experiments.

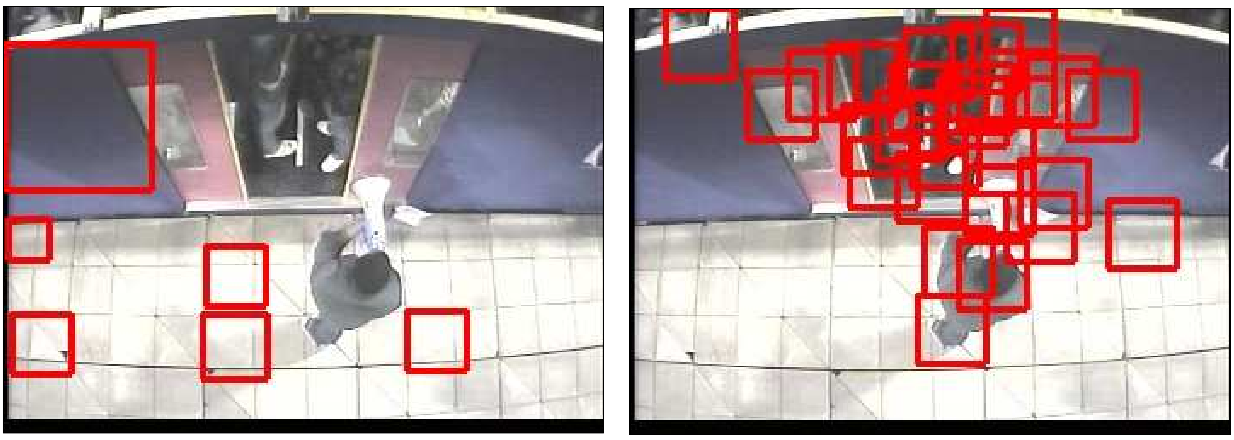

Figure 6 *– Performance of the Viola–Jones method (left) and perceptron technique (right).*

COMMENTS

In this work we have shown different ways to get models and parameters to predict the dwell time in public transport stops: regression models and direct measure of marginal boarding and alighting times. New dwell time models and parameters have been delivered, which can be used in taking decisions regarding public transport system. These models and parameters can also be used in managing the capacity of stops in similar realities, which are critical issues in high-demand public transport systems.

At the theoretical level, this study showed the importance of some physical characteristics that explain the dwell time. Firstly, it seems that a non-zero optimal vertical gap exists for speeding up the boarding and alighting processes. In addition, our results suggest that the door width is a more important issue than the platform height for the same objective. It was also observed a reduction in the boarding time if the fare is collected outside the vehicle, in particular for wide-door vehicles (up to 20% less). In addition, in wide-door vehicles the alighting time is reduced by 40% compared with narrow-door ones.

With respect to the use of artificial vision techniques for data processing, an interesting outcome was to discover the simplicity of the technique developed in this work when compared with the standard Viola-Jones method. Our results showed that it is possible to seriously consider the development of fully autonomous artificial vision systems to improve the data processing for experiments like the one presented in this article.

In the light of our findings, the research is still in progress seeking to improve the explanatory value of dwell time variables and parameters. One issue that will be answered with new data collected during 2009 is how different levels of vehicle occupation may affect our results. Other experiments will shed light on the impact of platform density in dwell times. These aspects are being further studied in full-scale experiments in the PAMELA laboratory of University College London.

For the general interest of the work, we believe it is appropriate for professionals who are working on public transport agencies in the design and evaluation of new services. It is also useful to researchers in the field of modelling of public transport in its various levels, due to stop operations are being incorporated with increasing frequency in transport modelling.

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