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In search of passenger saturation flows through transit doors

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Abstract In previous studies the authors have shown passengers' boarding and alighting times for the Transantiago system obtained at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) of University College London. Following this line of research, the aim of this paper is to demonstrate the existence of pedestrian saturation flows in public transport doors and show some values of this variable under different conditions. The methodology to achieve this aim was real-scale experiments performed in the Human Dynamics Laboratory at Universidad de los Andes in Santiago de Chile. Different groups of people getting off a mock-up of a public transport vehicle were recorded by means of video cameras. The videos were then visually processed to find values of passenger saturation flow according to door configurations. The variable studied was the width of the door. Results indicate that it is possible to define values of passenger saturation flows for different characteristics of public transport doors. These values proved to be statistically sensitive to the width of the door. In addition, results indicate that there seems to be a door width for which the flow of passenger reaches its optimum rate.

Keywords: Public Transport · Passengers · Saturation Flow · Door Capacity

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1 Introduction

A main challenge for public transport is to provide a good level of service. This is focused on quantitative and qualitative characteristics of the journey. One of the most important variables that affect the level of service is dwell time. This variable is defined as the time that a public transport vehicle remains stopped while transferring passengers, including acceleration and braking time (TRB, 2000).

Dwell time depends on the number of boarding and alighting passengers and how quick they carry out these tasks. The speed of passengers is determined by the fare collection method, internal layout of vehicles and the density of passengers. However as it is said in the Transit Capacity and Quality of Service Manual the most important variable that affects dwell time is the number of doors, because “the greater the number of door channels, the less time required to serve a given passenger flow” (TRB, 2003: 23).

Passenger flow for public transport doors is defined as the number of passengers that pass through a car doorway width. The data can be partitioned into boarding, alighting or mixed flow. When this flow reaches the highest value it can be called passenger saturation flow, similar to the concept of vehicle saturation at junctions.

According to Akcelik (1995), saturation flow is used at junctions as a basic characteristic to calculate the capacity of a traffic signal approach during a typical signal cycle (C). For a given junction approach, saturation flow is defined as the maximum discharge rate of a queue of vehicles during the effective green time (g) of that approach, as shown in Figure 1. At the start of the green period (G) there is a transient period (L1), called start loss, before the discharge rate reaches its maximum, which is the saturation flow (S) for that approach. If the queue remains until the start of the amber time (A), there is another transient period (L2), called end gain, until the start of the red time (R). Thus, the effective green time is defined as $g = G - L1 + L2$. The value of the saturation flow and transient periods depend on both the traffic composition and geometry of the junction approach. The relationship between saturation (S) and capacity (Q) of a traffic signal approach is $Q = uS$, where $u = g/C$.

The histogram shown in Figure 2 shows the discharge of vehicles during 0.1min if the queue remains until the end of the amber time. In this example, the green plus amber time is 0.7min or 42 seconds. The hypothesis shown in this paper is that the same sort of discharge curve of passengers may be found at public transport doors. That is, an alighting process of a bunch of passengers through a public transport door is similar to the discharge of a queue of vehicles at a traffic signal. Therefore, the aim of this paper is to measure passenger saturation flows through public transport doors by mean of real-scale experiments in the Human Dynamics Laboratory at Universidad de los Andes in Santiago de Chile, called HDL hereafter.

This article is made of five sections, including this introduction. In the second chapter the literature review on boarding and alighting times as well as door capacity is summarized. Next, in chapter three the methodology for obtained passenger saturation flows is shown. Results and analysis are presented in chapter four. Finally, the conclusions of this research are provided in chapter five.

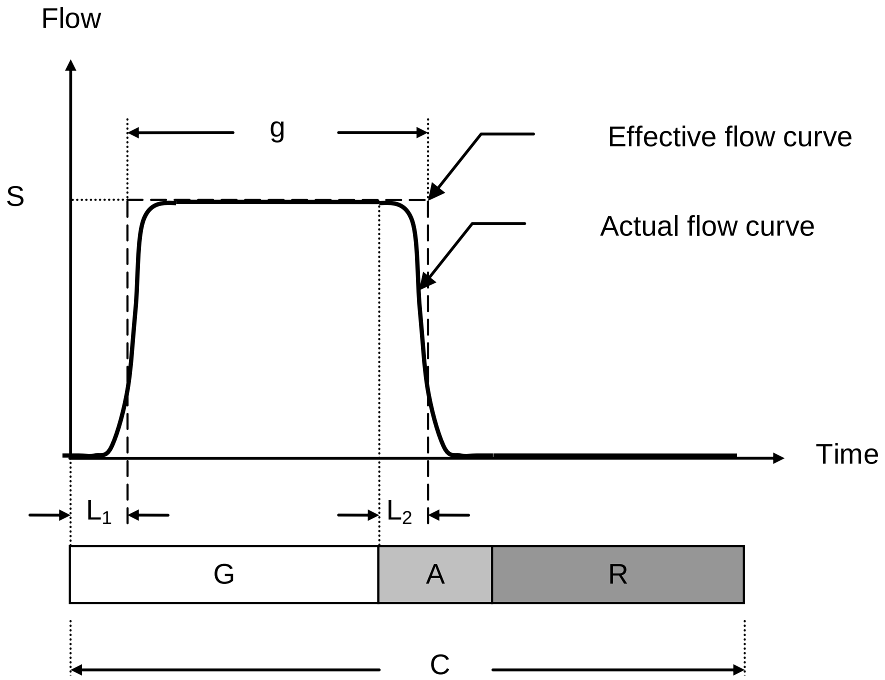


Fig. 1. Theoretical flow discharge at a traffic signal

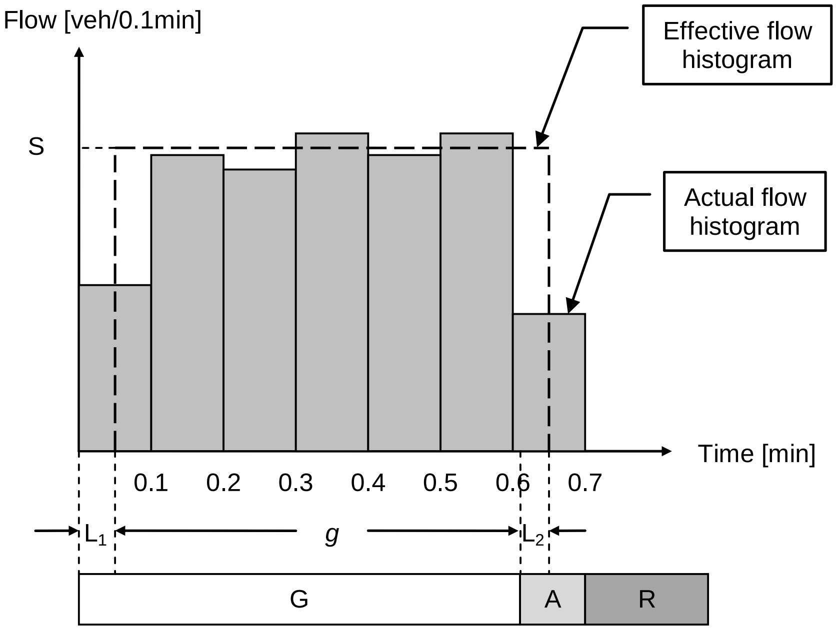


Fig. 2. Actual flow discharge at a traffic signal

2 Literature Review

Experiments in a real-scale mock-up of a bus at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) of University College London were conducted to obtain boarding and alighting times per passenger (Fernández, 2011). In these experiments, the effect of four variables was studied: platform height, door width, fare collection method, and density of passengers inside the vehicle. More than 300 video records of boarding and alighting processes were obtained in those experiments.

It was found that for the same passenger density inside the bus there is a range of boarding and alighting times per passenger, so that the coefficient of variation ranges from 11% to 29%. It was also shown that, as passenger density inside the bus increases, boarding times increase almost linearly from 0.9 to 2.0 seconds per passenger, but the alighting times increase exponentially from 0.6 to 6.0 s/pass. Interesting, passengers take longer to get on than to get off the vehicle up to a density of 4 passengers per square meter; above that density the situation reverses because the congestion inside the vehicle makes it more difficult for a passenger to reach the exit door.

In relation to door widths and their relationship to the dwell time in trains, TRB (2003) states that between 1.14 and 1.37m-width there is no major change in dwell time, reaching average values of 1.77 s/pass during alighting processes, 1.99 s/pass during boarding processes and 2.68 s/pass for two-way flow; i.e., boarding and alighting processes. The same reference states that a door with steps approximately doubles the time of boarding and alighting in relation to a door without steps.

Schelenz et al (2013) stated that the number of doors can affect directly the time of boarding and alighting. This can be proved by simulation. For example, a bus with 5 doors get an average dwell time of 19.22 seconds; 39% shorter than a bus with 3 doors. Similarly, Schelenz et al (2012) compared the alighting and boarding times with respect to the number of passengers and doors. For example, for a 3-door bus, when the number of passengers increases from 30 to 60, the average alighting time goes up by nearly 4 seconds. Rexfelt et al (2014) used a mock-up of a public transport vehicle to prove that a bus with 4 doors will have a dwell time 17% lower than a bus with 3 doors. However those studies did not consider variations of door width.

Other authors (Schadschneider et al, 2009) state that the capacity of bottlenecks (like doors in a corridor) can grow with increased width. When pedestrians are formed in lanes, the capacity will be increased only if a new lane is formed. This is shown in different models (Predtechenskii and Milinskii, 1978; Hoogendoorn and Daamen, 2005; Kretzet al, 2006; Nagai et al, 2006

The closest work related with our research is Daamen et al (2008). They studied the boarding and alighting times with respect to different vertical and horizontal gaps and door widths in rail vehicles by performing laboratory experiments. According to Daamen et al (2008) the capacity of public transport doors decreases when gaps (vertical and horizontal) increase. However, for small vertical gaps, door capacity slightly increases as horizontal gap increases. They also found that capacity decreases up to 25% if passengers are carrying luggage.

Following the work of Daamen et al (2008), Daamen and Hoogendoorn (2010) identified the relation between door capacity and four experimental variables (door width, population, light intensity and the presence of an open door) in evacuation conditions.

3 Methodology

To obtain passenger saturation flows we used the method described in the Road Note 34 (RN34) of the Road Research Laboratory (RRL, 1963) for measuring vehicle saturation flows at traffic signals. It consists of counting the number of vehicles crossing the stop-line in successive intervals during a saturated green period, as shown in Figure 2. As an example of the RN 34 method, Table 1 shows its application at a traffic signal in Santiago de Chile.

Table 1. RN34 method applied in a traffic signal in Santiago de Chile

Green plus Amber periods	0.1-min intervals						Last interval	
	1	2	3	4	5	6	Vehicles	Time (s)
1	1	2	3	3	2	3	2	2.00
2	1	3	2	2	3	3	2	2.83
3	1	2	3	3	2	3	1	3.33
4	1	4	2	3	3	3	2	2.00
5	1	3	2	3	3	2	3	1.00
6	2	2	3	4	4	1	1	2.33
7	1	3	3	4	3	3	1	2.50
8	1	2	3	4	2	2	2	2.00
9	1	3	3	3	3	2	2	2.25
Total	10	24	24	29	25	22	16	20.24
Sample	9	9	9	9	9	9	9	9
Average	1.11	2.67	2.67	3.22	2.78	2.44	1.78	2.25

As shown in the table, nine green plus amber fully-saturated periods of 36 seconds are shown. Following RN34, each green plus amber period was divided into 0.1-min or 6-s intervals, plus a last interval of variable length. In this example six 6-s intervals give 36-s green plus amber time. The saturation flow is calculated as the average ratio between the number of vehicles and the number of saturated green plus amber periods, excluding the first and the last interval. In this case, the saturation flow is S = 2.76 veh/0.1-min; i.e., 1653 veh/h. This is a typical value when there are only light vehicles but various types of movements at the junction (Akcelik, 1995).

Figure 3 shows the discharge histogram at this junction, where the dotted line is the average height of the saturated intervals (intervals 2-6); in other words, the saturation flow. As can be seen in the figure, there are differences in the height of the saturated intervals and the difference between two adjacent saturated intervals is about 20%.

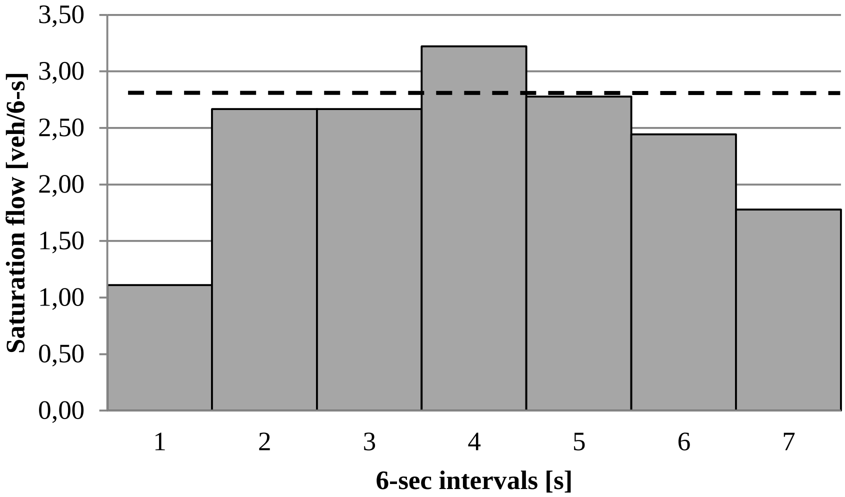


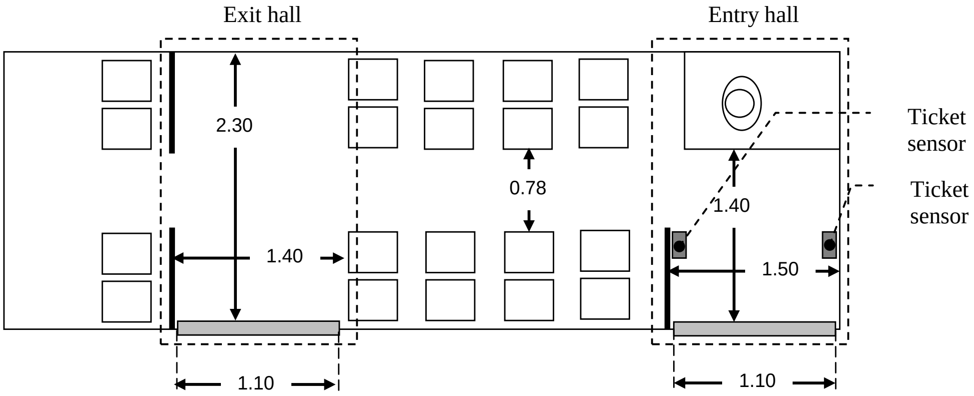
Fig. 3. Example of a flow discharge at a traffic signal in Santiago de Chile

In order to achieve the same condition for public transport doors, unrestrained discharges of passengers were studied. As a result, alighting processes are needed from public transport vehicles in which passengers are not obstructed by the congestion caused by them. This condition is difficult to obtain in real systems with enough of alighting demand because physical restrictions as the width of the platform produce interactions between passengers. Therefore, a controlled environment could be necessary such as a laboratory and a real-scale mock-up. This environment was provided for this study by the HDL.

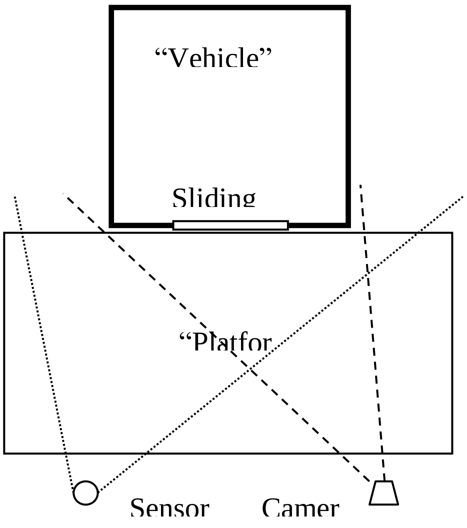
Saturation flow was measured according to the RN34 but applied to the passenger alighting process. We divided the alighting period into 2 or 3-sec intervals and counted the number of passengers in each interval from the time the door is opened until all the passengers have gotten off the vehicle. Then a histogram that represents the alighting period is constructed. The width of the intervals was chosen in order to have at least 4 saturated intervals according to the minimum subjects in each experiment (20 people).

In the application of RN34 to passengers, the first interval starts when the doors start to open, because passengers jump off the vehicle as soon as they see a gap in the door. Then the average height of the saturated intervals gives the saturation flow. Intervals belong to the start loss period; and those in which there is no more saturation are not considered for the calculation. To decide when saturation ends, we observe that the height of an interval is clearly below the average height of the saturated intervals. We applied a 20% drop in the height of the interval to take this decision, according to that observed in Figure 3. Obviously, there is no final transient because there is nothing similar to the amber period in the case of passengers. On the contrary, when everybody gets off the train, the measurement stops.

The HDL was designed to study human dynamics; from parts of the body to groups of people. In these experiments, a mock-up of the hall of a public transport vehicle was built for our study. Figure 4 shows the concept and the layout of the mock-up.



a) Entry and exit halls of a public transport vehicle



b) Layout of the mock-up

Fig. 4. Mock-up in the HDL at the Universidad de los Andes

In order cover any type of vehicle - from normal buses to metro cars - the mock-up of the hall is 3-m long by 2.5-m wide with a door in the middle which can be opened up to 2-m wide. At both sides of the hall there is a 0.8-m doorway to represent the aisle of the vehicle. The size of the platform is variable according to the transit system to be investigated.

We tested door width as a control variable (Fernandez et al 2013); therefore, a zero vertical gap was assumed. Seven door widths were tested: 600, 800, 1100, 1300, 1650, 1850, and 2000 mm. These numbers were chosen because they represent the different doors of public transport vehicles in Santiago de Chile: small buses (600 and 800 mm), normal and articulated buses (1100 mm), and metro cars (1300 and 1650 mm). As far as we know, 1850-mm and 2000-mm doors do not exist in urban transit systems. We chose these two extreme values to see the passenger behavior under a reality which can only be tested in laboratory. A number of 10 alighting processes were recorded for each width, making a total of 50 observations. In each alighting process, 26 students acting as passengers get off the vehicle. The instruction given to passengers was “please get-off the vehicle as if you were to continue your journey on foot during the rush hour”.

4 Results and Analysis

Experiments showed similar histograms of the alighting processes to those found in Figure 3 for a traffic signal. Figure 5 shows 4 intervals of three second each for which the saturation flow is 4.389 passengers per 3-sec interval or 1.47 passengers per second for an 800-mm door. The first interval represents the start loss and the last two ones are the end of the saturation, because the flow difference between the 5th and 6th intervals is more than 20% (24%). In Figure 6 the same is shown for a 1300-mm door. In this case, the saturation flow is 5.2 passengers per 2-sec interval; i.e., 2.60 passengers per second. In this case, the flow difference between the 5th and 6th intervals is 66%.

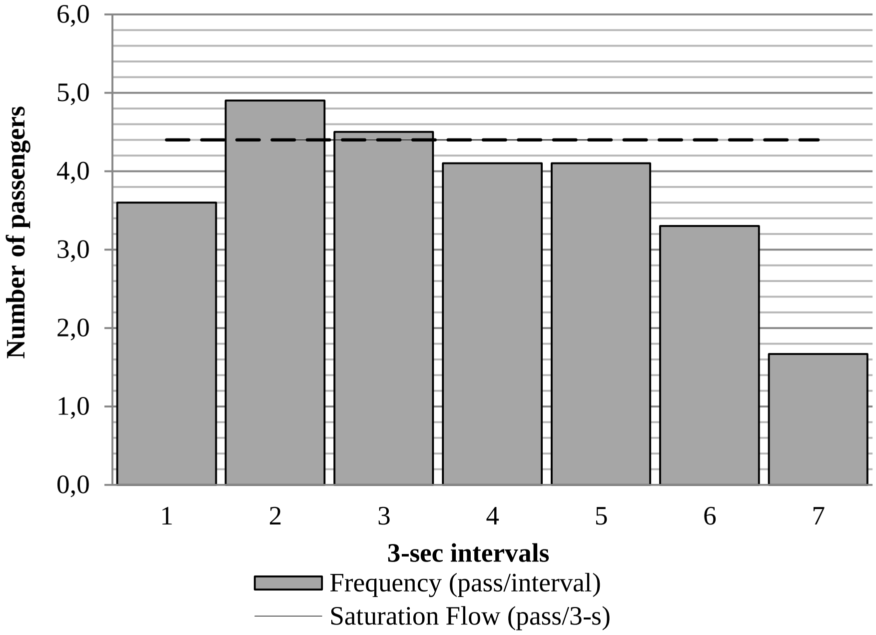


Fig. 5. Histogram of an alighting process for an 800-mm door

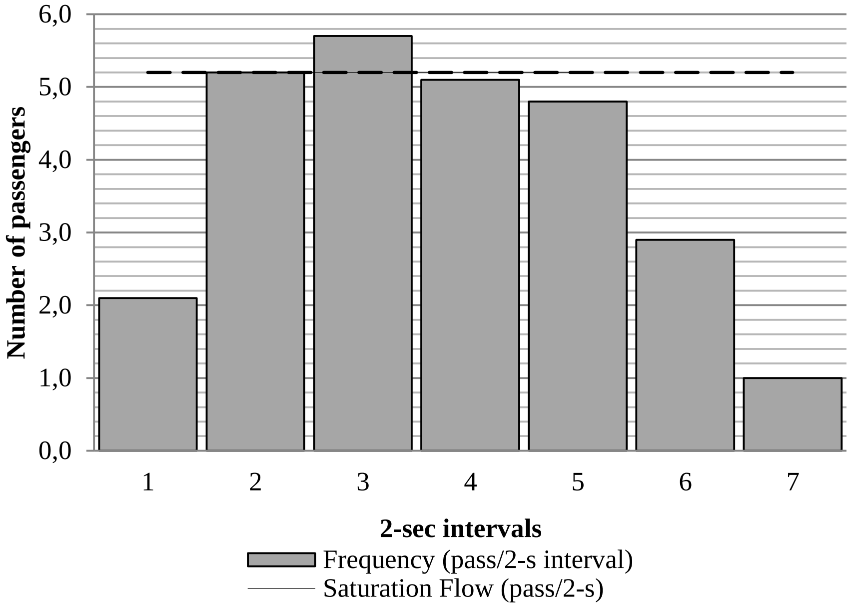


Fig. 6. Histogram of an alighting process for a 1300-mm door

In summary, results obtained at the HDL, in passenger per second and passenger per second per meter, are shown in Table 2 and Figure 7.

Table 2. Values of passenger saturation flow in the HDL

Door width (mm)	Saturation flow (pass/s)	Saturation flow (pass/s-m)
600	1.093	1.822
800	1.467	1.833
1100	2.067	1.879
1300	2.600	2.000
1650	3.400	2.061
1850	3.680	1.989
2000	3.840	1.920

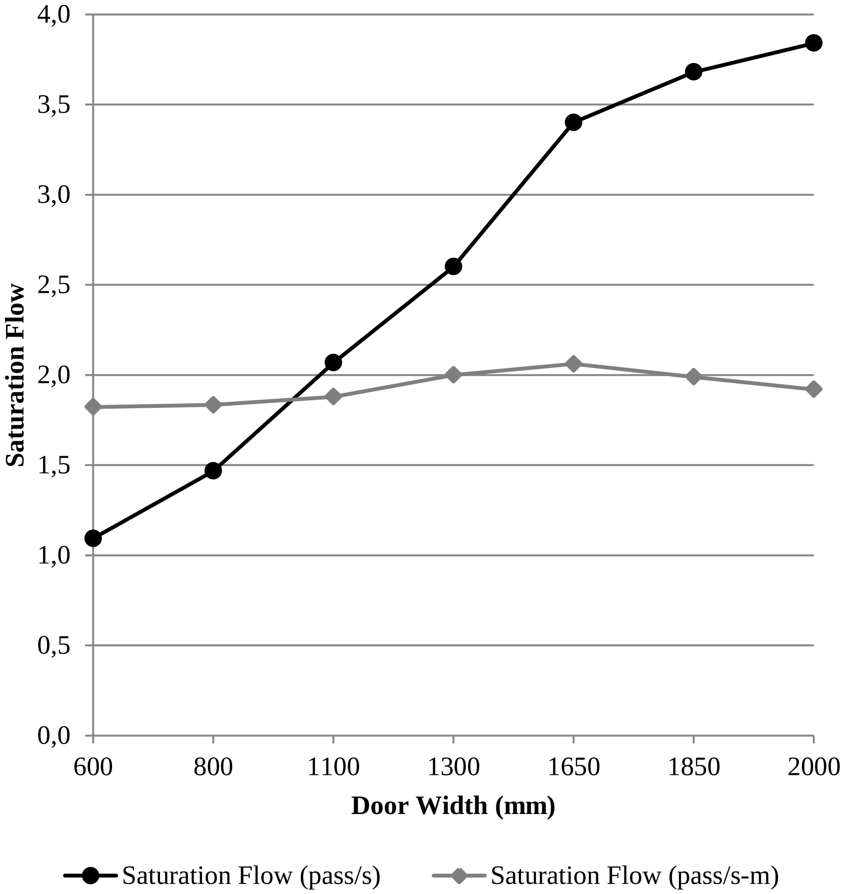


Fig.7. Behavior of passenger saturation flow for the study cases in the HDL

As can be seen in the figure, the passenger saturation flows in passenger per second grows with the door width, as expected. However, there seems to be a decreasing return as the doors become wider. In fact, from 1650 mm, the rate of increase in the saturation flow decreases. This is more apparent if we observe the saturation flow in pass/s-m. Clearly, the highest saturation flow is reached for a 1650-mm door.

5 Conclusions

The first conclusion of this work is that the same sort of discharge curve of vehicles at signalized junctions can be found in doors of public transport for passengers. Obviously, the discharge curves cannot be identical, because of the different nature of the discharge regulation. In the case of vehicles, regulation is carried out by a traffic signal with red, green and amber indications. For passengers, a door opens and closes, an alarm sounds, or all passengers alight. The last case is similar to a traffic signal in which the queue of vehicles clears before the amber period: during some intervals at the beginning of the green period, the saturation flow can be measured.

The theoretical consequence is that the capacity of a public transport door cannot be considered just as the inverse of the average boarding or alighting time per passenger. This is because of the existence of an initial transient period and a final decay in the flow rate as the bunch of passengers inside the vehicle decreases. Therefore, the capacity of a public transport door is the inverse of the headways during the saturation period. As far as we know, this concept has not been reported in the literature, despite the important contributions mentioned in the literature review.

It was found in this work that passenger saturation flows depends on the width of the door. Thus, the values found in this study are in the range between 1.8 and 2.0 passengers per second per meter.

In relation to the methodology, it is important to mention the successful application of the RN 34 approach for pedestrians. We can say that the RN 34 can also be used for the estimation of pedestrian saturation flows. In order to do that, it is only necessary to change width of intervals. Despite the reduction in the time width of the intervals, the number of saturated intervals in the HDL experiments was no more than 4 intervals. We found that they are sufficient, looking at the cases of vehicle saturation flows; with no more than 5 saturated intervals a ground truth value is obtained.

The work done so far indicates that some advances on public transport planning and operations are only possible through real-scale laboratory experimentation. Therefore, further research on passenger saturation flow in public transport doors at the HDL may involve the following: Explore values of vertical gaps to see if an optimum can be found; study the effect of the passenger density inside the vehicle; test the effect of the location of horizontal and vertical handrails inside the vehicle.; explore the effect of the physical and operational design of the platform.

Finally, further studies can be performed to obtain pedestrian saturation flows in other pedestrian devices, such as turnstiles, pedestrian crossings, andrevolving doors.

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