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## Experimental study for estimating capacity of cycle lanes

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### Abstract

Today some cycle lanes are reaching high levels of flow. Clear examples are the cycle-track Pucuro in Santiago de Chile and the cycle-lane Tavistock Square in London. The problem presented in this research is the lack of measurements for estimating the capacity of cycle lanes at traffic signals. Therefore, it cannot be identified through indicators whether cycle lanes are saturated or not. For this reason there is no record of the capacity they can offer. As a methodology we established four steps. Firstly, we measured the physical and operational variables of cycle lanes, and we investigated about international studies related to their capacities. Then we used the approach of the Road Note 34 (RRL, 1963) to measure the saturation flow and transient periods of cycle lanes, taking as case study Santiago de Chile and London. In addition, we defined different scenarios of experiments. Finally, the results were transformed into design recommendations to provide an adequate level of service for cyclists. The main results of this research shows that the saturation flow grows almost linearly with the width. When cyclists formed in lanes, the saturation flow increased only if a new lane was formed. In the case of the cycle-track Pucuro, for a width of 1.0 m the saturation flow reached 2070 bicycle/h-lane. If the width increased to 2.0 m, the saturation flow reached 4657 bicycle/h-lane. In relation to Tavistock Square, this cycle-lane (width of 1.0 m) reached a saturation flow of 4320 bicycle/h-lane. As a conclusion, this research can be used by traffic engineers to estimate the saturation flow of cycle lanes and delays of cyclists at traffic signals. This in turn can help in designing cycle facilities at transport infrastructures. The validation of our investigation can also help transport planners with the calculation of the capacity, optimum width, comfort, and other operational costs of cycle lanes.

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### 1. Introduction

Today some cycle lanes of Santiago are reaching high levels of flow. According to the consultant Urbanism and Territory (2013) cycling is growing at a rate of 20% annually. This is observed mainly at peak hours which occur between 7-10 am when cyclists are heading to their jobs, schools or universities, and in the afternoon between 19 – 21 pm when returning home.

Clear examples of high flow of bicycles in Santiago are the cycle-track Pocuro, cycle-track Andres Bello, cycle-lane Antonio Varas and cycle-lane Simon Bolivar. Similarly, in developed cities like London, where 2% of the trips per day are done by bike (TfL, 2011), there are also some cycle lanes reaching high levels of flow, for example the cycle-lane Tavistock Square.

The problem presented in this research is the lack of measurements for estimating the capacity of cycle lanes at traffic signals. Therefore, it cannot be identified through indicators whether cycle lanes are saturated or not. For this reason there is no record of the capacity they can offer.

According to Akcelik (1995) the saturation flow in vehicles is a basic characteristic to calculate the capacity of a traffic signal approach during a typical signal cycle (C). For a given junction approach, the 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 Fig. 1. At the start of the green period (G) there is a transient period ( $\lambda_1$ ), 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 ( $\lambda_2$ ), called end gain, until the start of the red time (R). Thus, the effective green time is defined as  $g = G - \lambda_1 + \lambda_2$ . The value of the saturation flow and transient periods depend on both the traffic composition and geometry of the junction approach. The curve shown in Fig. 1 comes from the discharge of a queue of vehicles from a traffic signal which remains until the start of the red period. This sort of traffic behavior is obtained if there is no blockage downstream the stop line; e.g., the downstream street is not blocked by the back of a queue of vehicles which may reduce the discharge rate.

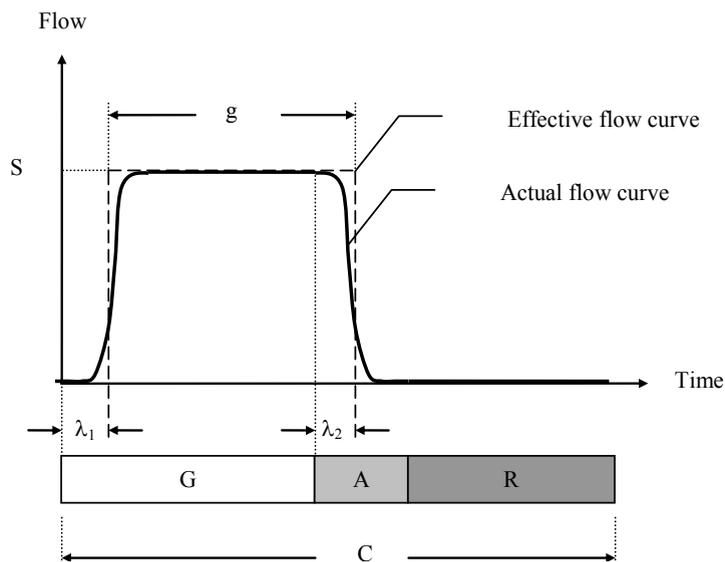


Fig. 1. Typical flow discharge at a traffic signal.

The flow-time curve shown in Fig. 1 indicates that not all vehicles in a queue take the same time to cross the stop line at a traffic signal. The question posed by this piece of research is: Could the same behavior occur in cycle lanes? Our hypothesis is that the same sort of discharge curve of cyclist can be found at cycle lanes.

Following this hypothesis, the aim of this paper is to study the estimation of saturation flows of cycle lanes under different physical configurations, taking as case study Santiago de Chile and London. This includes the following specific objectives: (a) measure the physical and operational variables of cycle lanes and compare them with international standards; (b) measure the saturation flow of cycle lanes using an analytic method; (c) identify factors that can affect the saturation flow of cycle lanes; (d) propose design recommendations for cycle lanes.

This paper is made of six chapters, including this one. In Chapter 2 a summary of the literature review on the topic is presented. In Chapter 3 the case study is described. Next, in Chapter 4 the methodology followed for this work is explained. Chapter 5 presents the results obtained. Finally, in Chapter 6 some conclusions and recommendations are delivered.

## 2. Literature Review

The capacity of cycle lanes depends on the characteristics and type of route (e.g. width, gradient and behavior of cyclists). When there is an interrupted flow, e.g. signal traffic approach, the capacity ( $Q$ ) is calculated as equation (1):

$$Q = S \cdot u \quad (1)$$

In which  $S$  is the saturation flow [bicycle/h-lane] and  $u$  is the ratio between the effective green time ( $g$ ) and the typical signal cycle of that approach ( $C$ ).

In relation to the design of cycle lanes, the Chilean Manual REDEVU (MINVU, 2009) defines a cycle lane as a bicycle facility that can share space with other users (e.g. pedestrians or motorized traffic) and can be partially separated with divisors or marked by other virtual elements in the pavement (e.g. solid white stripe). This type of bicycle facility is permitted in streets where the maximum velocity of cars is 60 km/h. The minimum width of a cycle lane should be 0.875 m per lane. When a cycle lane is totally separated to other users by open areas, barriers or other physical elements it is called a cycle track. In a cycle track the minimum width should be 1.0 m per lane.

However, there isn't a unique standard for cycle lanes. For example, the HCM (2000) propose a minimum of 1.20 m per lane. In addition, Table 1 shows other studies (Miller and Ramey, 1975; Brilon, 1994) that proposes different widths for cycle lanes.

Table 1. Study of different widths for cycle lanes.

Country of study	Minimum width [m per lane]
Evanston, USA	0.75 – 1.40
Davis, California, USA	1.28
Holland	1.00
Germany	1.00
Sweden	1.20
China	2.50 m for 2 lanes; 1.00 m for an additional lane
Norway	1.60

As a consequence, Allen et al (1998) states that there are different studies that calculate the capacity of cycle lanes. For example, the HCM (2000) defines 1600 bicycles per hour per lane as the capacity for two-way facility and 3200 bicycles per hour per lane for one-way facility. These values are under uninterrupted-flow conditions. However, under interrupted-flow conditions (e.g. traffic signal approach) the HCM (2000) propose a saturation flow of 2000 bicycles per hour for a one direction bicycle lane. Also Table 2 shows other studies (Stembord, 1991; Botma, 1995) of capacity for cycle lanes.

As it can be seen in Table 2 there are different values for the capacity of cycle lanes and there is no clear references to identify which one is the correct capacity for a traffic signal approach.

Table 2. Study of different capacities for cycle lanes.

Country of study	Width [m per lane]	Capacity [bicycle/h-lane]
Sweden	1.20	1500
Canada	1.25	5000
China	1.00	1800 – 2100
Germany	1.00	3200
Germany	0.78	3000 – 3500

### 3. Case of Study

To study the capacity of cycle lanes two cases were chosen. The first one is the cycle-lane Tavistock Square, which is located in London, UK. This two-way asphalt cycle-lane share the space with the motorized traffic and is partially segregated by divisors (see Fig. 2 – left). The total width of this cycle-lane is 2.0 m (1.0 m per lane). This cycle-lane reaches a bidirectional flow of about 1000 cyclist/h at peak hour (morning and afternoon).



Fig. 2. Cycle-lane Tavistock Square (left); Cycle-track Pocuro (right).

The second case is the cycle-track Pocuro, which is located in Santiago de Chile. As it shown in Fig. 2 (right) this two-way asphalt cycle-track is totally separated to other users (e.g. pedestrians or motorized traffic) by a green open area (Pocuro Park). Similar to Tavistock Square, Pocuro's total width is 2.0 m (1.0 m per lane). This cycle-track reaches a bidirectional flow of about 900 cyclist/h at the morning peak hour and 1300 cyclist/h at the afternoon peak hour. Also this cycle-track is an important route that connects two urban districts, with different physical and operational characteristics.

### 4. Methodology

We used the approach of the Road Note 34 – RN34 – (RRL, 1963) to measure the saturation flow of cycle lanes under different physical configurations. The RN34 describes a method for measuring vehicle saturation flow 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 Fig. 1. “The basis of this method is to divide the saturated portion of each green period into short intervals of time and to average the flows in those saturated intervals which are free from ‘lost time’ effects, to give a measure of the saturation flow...”(RRL, 1963:2). The RN34 also states that “...the method consists of recording the number of vehicles discharging from the queue in successive 0.1-minute intervals... When the flow is no longer at the saturation level because the queue has disappeared on one or more lanes the recording of the flow in 0.1-minute interval should be discontinued” (RRL, 1963: 4).

Table 3 shows the application of the RN34 at a vehicle traffic signal in Santiago de Chile. Nine saturated cycles are shown. Each cycle is divided into 6 intervals of 0.1-min (6 seconds) each, plus a last interval. The saturation flow

is calculated as the average of the ratio between the number of vehicles and the number of saturated cycles, excluding the first and the last interval. In this case, the saturation flow is  $S = (2.67 + 2.67 + 3.22 + 2.78 + 2.44)/4 = 2.76$  veh/0.1-min; i.e., 1653 veh/h. This means 1653 veh/h per lane, which is a typical value when there are only light vehicles but various types of movements at the junction, as in this case.

Table 3. RN34 method applied in a traffic signal in Santiago, Chile.

Cycle	0.1-min intervals						Las 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

Fig. 3 shows the discharge histogram at this junction, where the dotted line is the average height of the saturated intervals (intervals 2 to 5); in other words, the saturation flow. As can be seen in the figure, there are differences in the height of the saturated intervals; however, the difference between two adjacent saturated intervals is about 21%.

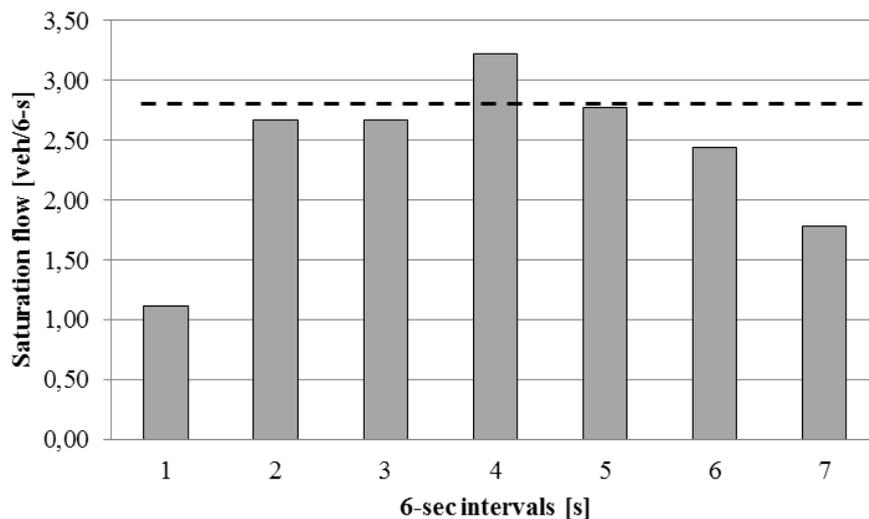


Fig. 3. Example of a flow discharge at a traffic signal in Santiago de Chile.

Fig. 4 shows another example of the measured saturation flow at a traffic signal in Santiago de Chile. This time the saturation flow was measured in the central lane of a 3-lane approach. The result is 2.41 veh/0.1-min or 1446 veh/h-lane. This value is also typical for a lane in which there are a single movement but heavy good vehicles in the traffic

stream, as in this case. As in the previous example the difference between two adjacent saturated intervals is less than 25%.

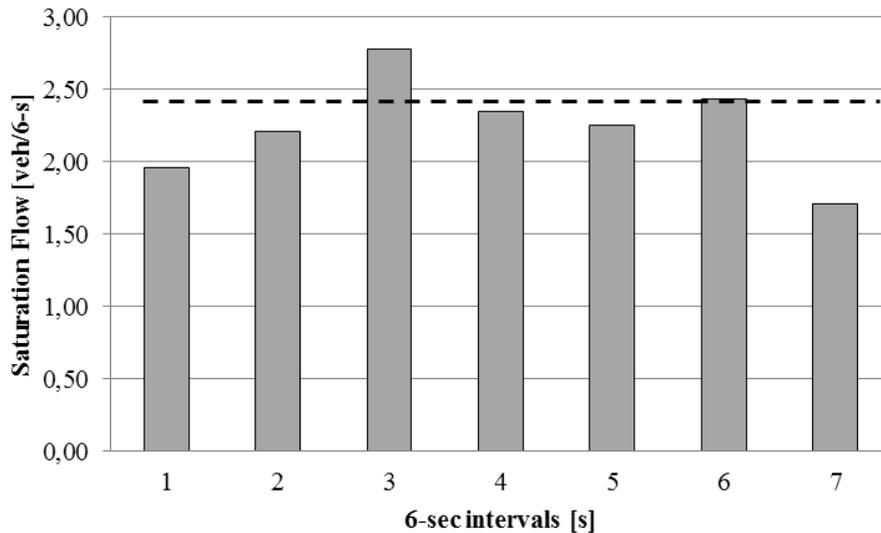


Fig. 4. Another example of a flow discharge at a traffic signal in Santiago de Chile.

In order to get the same conditions at cycle lanes traffic signals unrestraint discharges of cyclist must be studied. The saturation flow was measured according to the RN34 but applied to cyclist discharge process. We divided the alighting period into 1-2 sec intervals and counted the number of cyclist in each interval from the green period ( $G$ ) of the traffic signal approach. Then a histogram during the discharge period is made. The width of the intervals was chosen in order to have at least 4 saturated intervals, according to the minimum subjects for experimentation (more than 20 cyclists).

In the application of the RN34 to cyclists, the first interval starts when the green period ( $G$ ) begins. 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 the saturation ends, we observe that the height of an interval is clearly below the average height of the saturated intervals. As in the case of vehicles the criterion for this decision is that the flow in this interval is at least 20% lower than in the saturated ones.

#### 4.1 Cycle-lane Tavistock Square

In the case of the cycle-lane Tavistock Square we studied the traffic signal at the intersection of Tavistock Square and Tavistock Place. This traffic signal presented a green period ( $G$ ) less than 20 seconds for all cycles during the peak hour (morning and afternoon), so queues always were made at the end of each cycle.

In this case we recorded with video cameras only two periods of one day. The first period was recorded in Tuesday 8th of October 2013 during the afternoon peak hour (6:00 pm to 7:00 pm). The second period was recorded in Wednesday 9th of October 2013 during the morning peak hour (8:30 am to 9:30 am).

It must be noted that in London before the green period starts there is an amber time to prepare cyclist for the discharge process.



Fig. 5. Tavistock Place/Tavistock Square: Morning peak hour (left); Afternoon peak hour (right).

#### 4.2 Cycle-track Pocuro

Unlike Tavistock Square, cycle-track Pocuro presented a green period ( $G$ ) of more than one minute at each traffic signal junction, so all cyclists could discharge without obtaining a queue at the end of the cycle. Therefore, to simulate similar conditions to Tavistock a controlled environment was provided in a section of the same cycle-track with a green period of only 10 seconds (see Fig. 6).



Fig. 6. Experiments in controlled environment at cycle-track Pocuro.

In this environment 20 students were recruited to participate as cyclists. The participants were 20% female and 80% male, who commonly used this cycle-track. When the cyclist passed the traffic signal the cyclist must enter again to the cycle-track and repeated the discharge. As a consequence a queue always was made at the end of the cycle. To calculate the saturation flow we performed different experiment scenarios to analyze the variation with respect to the width. This is: (A) 1.0-m lane; (B) 1.25-m lane; (C) 1.5-m lane; (D) 2.0-m lane. A number of 20 discharge processes were recorded for each width, making a total of 80 observation.

## 5. Results

### 5.1 Cycle-lane Tavistock Square

Fig. 7 and Fig. 8 shows the discharge histogram of the cycle-lane Tavistock Square (traffic signal at the intersection of Tavistock Square and Tavistock Place).

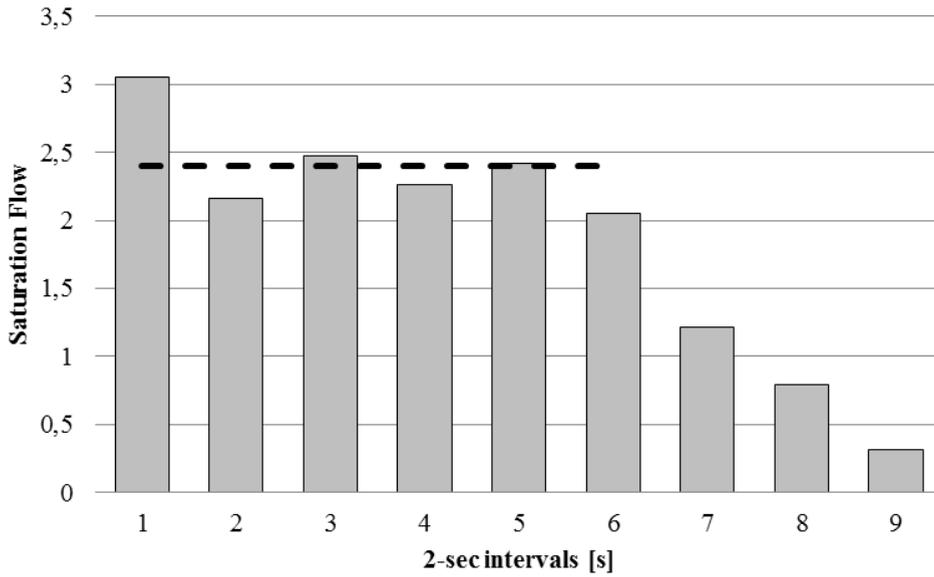


Fig. 7. Flow discharge at cycle-lane Tavistock Square at the morning peak hour.

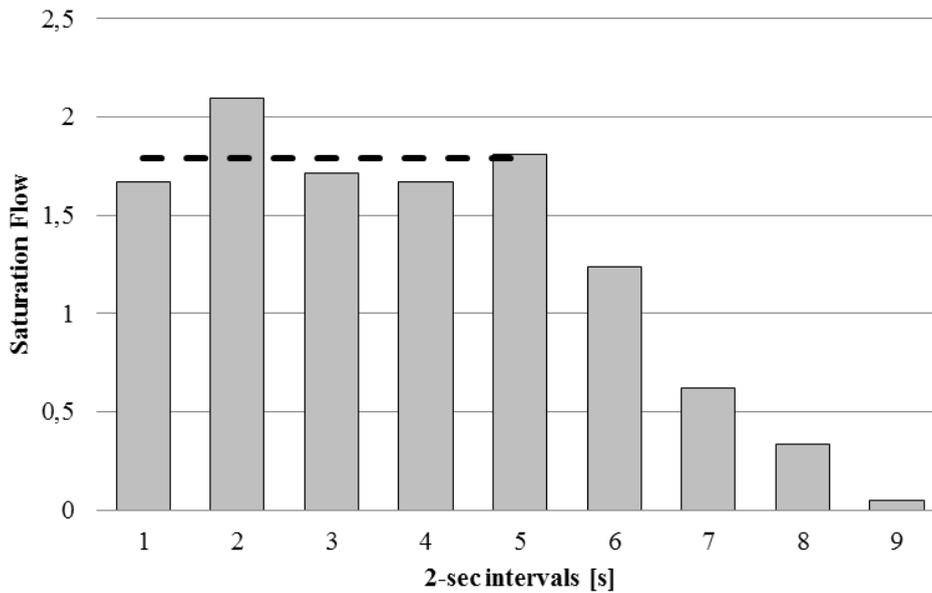


Fig. 8. Flow discharge at cycle-lane Tavistock Square at the afternoon peak hour.

The dashed line in the figures represent the saturation flow, which is the average height of the saturated intervals (1 to 6 in Fig. 7 and 1 to 5 in Fig. 8). At the morning peak hour the saturation flow was measured in direction East-West, reaching 2.40 bicycles/2-sec or 4320 bicycle/h-lane. At the afternoon peak hour the saturation flow was measured in direction West-East, reaching 1.79 bicycles/2-sec or 3222 bicycle/h-lane (25% less than the morning peak hour). It must be noted that in both cases (morning and afternoon peak hour) the green period ( $G$ ) was equal to 19 seconds. In relation to transient periods,  $\lambda_1$  (start loss) was equal to zero which means that the saturation flow started at the first interval. This could be caused because in Tavistock Square the amber time prepared cyclists to discharge at the traffic signal before the green period started. Respect to  $\lambda_2$  (end gain), it was measured a value of 2 seconds. Therefore, the effective green time ( $g$ ) was 17 seconds.

5.2 Cycle-track Pocuro

Fig. 9 to Fig. 12 shows the discharge histogram at the experiments in the controlled environment at cycle-track Pocuro. The dashed line in each figure represents the saturation flow (average height of the saturated intervals: 1 to 8). The figures shows that the saturation flow grows almost linearly with the width. When cyclists formed in lanes, the saturation flow increased only if a new lane was formed.

In Scenario A (1.0-m lane) one lane of cyclist were formed and the saturation flow reached 0.57 bicycles/1-sec or 2070 bicycle/h-lane. As it was expected when the width of the lane increased to 1.25 m (Scenario B), two lanes of cyclists were formed and the saturation flow raised by the same proportion (25% compared to Scenario A) reaching a value of 0.71 bicycles/1-sec or 2587 bicycle/h-lane.

In the other scenarios the saturation flow also increased in a similar proportion than the width. For example, in Scenario C (1.50-m lane) the saturation flow increased by 66% compared to Scenario A reaching a value of 0.95 bicycles/1-sec or 3442 bicycle/h-lane. Also, in Scenario D (2.0-m lane) three lanes of cyclists were formed and the saturation flow was almost 2.5 times the value compared to Scenario A, reaching a value of 1.29 bicycles/1-sec or 4657 bicycle/h-lane.

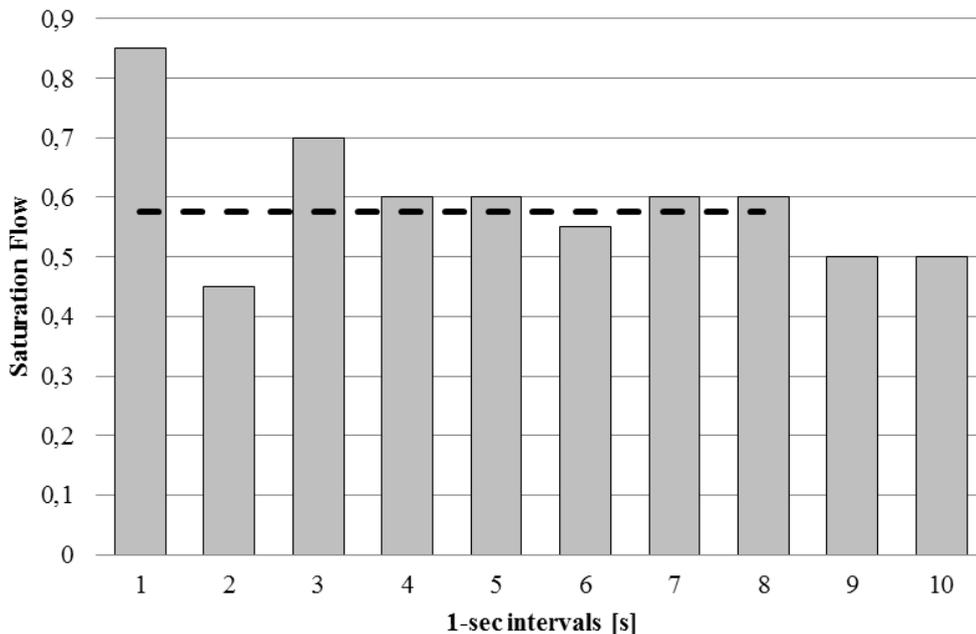


Fig. 9. Flow discharge at cycle-track Pocuro – Scenario A (1.0-m lane).

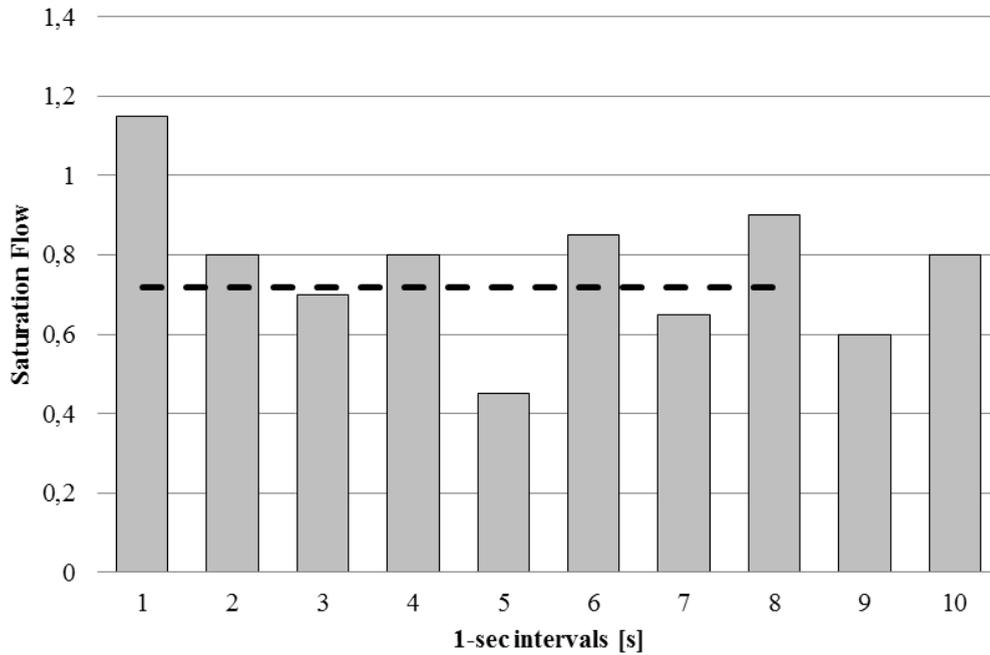


Fig. 10. Flow discharge at cycle-track Pocuro – Scenario B (1.25-m lane).

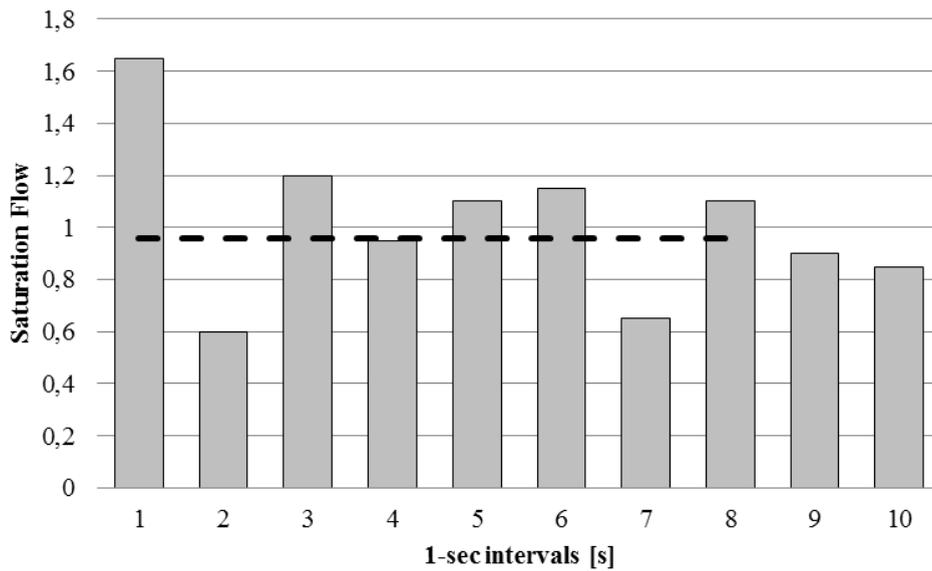


Fig. 11. Flow discharge at cycle-track Pocuro – Scenario C (1.50-m lane).

In relation to the green period ( $G$ ) the cycle-track was simulated with 10 seconds. Similar to Tavistock Square the cycle-track Pocuro presented a transient period of start loss ( $\lambda_1$ ) equal to zero in all scenarios. This was produced because at the experiment cyclists were instructed to be ready to discharge at the traffic signal (simulating the amber time before the green period). With respect to end gain period ( $\lambda_2$ ) at cycle-track Pocuro, a value between 0 to 0.6 sec was measured. Therefore, the effective green time ( $g$ ) was practically the same as the green period ( $G = 10$  s).

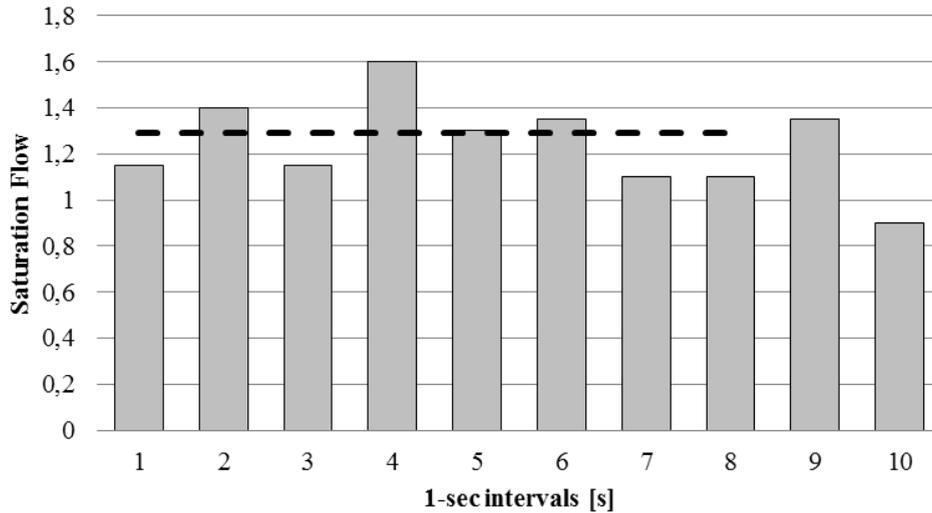


Fig. 12. Flow discharge at cycle-track Pocuro – Scenario D (2.0-m lane).

## 6. Comments and Recommendations

In this paper, we have firstly validated the hypothesis under interrupted-flow conditions (signal traffic approach) at cycle-lane Tavistock Square. In this cycle-lane the saturation flow reached a value of approximately 4300 bicycle/h-lane at the morning peak hour and 25% less (3200 bicycle/h-lane) at the afternoon peak hour. Secondly, we observed that cycle-track Pocuro (1.0-m lane) reached a saturation flow of about 2000 bicycle/h-lane. If the width increases the saturation flow will also rise reaching a maximum value of approximately 3400 bicycle/h-lane (for 1.5-m lane). If the cycle-track is 2.0-m-wide the saturation flow reaches almost 4700 bicycle/h-lane, which is practically the double than the 1.0-m lane. In other words, the saturation flow grows almost linearly with the width (see Fig. 13). When cyclists forms in lanes, the saturation flow increases only if a new lane is formed.

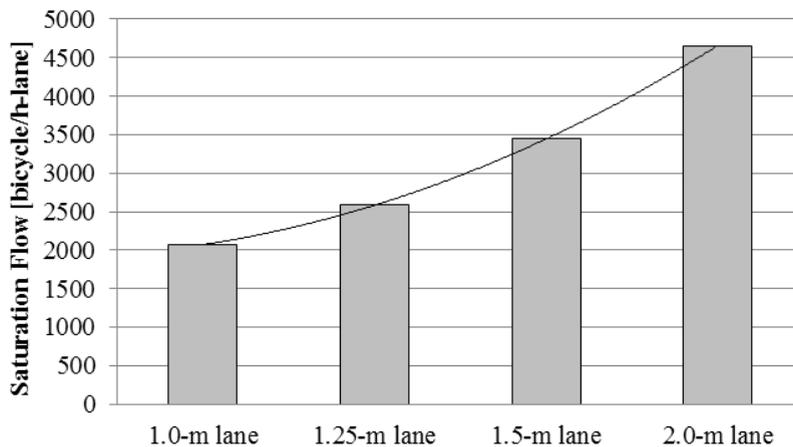


Fig. 13. Summary results: saturation flow for each width at cycle-track Pocuro.

Thirdly, if we compare the two bicycle facilities it can be seen that the saturation flow of cycle-lane Tavistock Square (1.0-m lane) is about the double than the saturation flow of cycle-track Pocuro (1.0-m lane). This can be caused

because at the cycle-track Pocuro cyclists had more obstacles such as trees, pedestrians, urban furniture or other elements that affected the discharge at the traffic signal approach. Also the difference can be attributed to the experiment, in which cyclists were students and not real commuters. In this sense, to validate the hypothesis for the cycle-track Pocuro we need to do more experiments with a higher amount of cyclists and other flow constrains at the junctions. Fourthly, as the saturation flow and transient periods depend on both the traffic composition and geometry of the junction approach, we recommended to use marking or any other element in the pavement to reduce conflicts. In the case of cycle-track Pocuro, the use of cones produced one formed lane for cyclists (Fig. 14 – right) instead of multiple lanes without an order (Fig. 14 – left). Moreover, cyclists felt safer because each of them maintained in the lane (formed by the cones) without overpassing others cyclists or running down a pedestrian.



Fig. 14. Cycle-track Pocuro: without cones (left); the cones in the pavement avoid conflicts between cyclists and pedestrians (right).

In conclusion, this research can be used by traffic engineers to estimate the saturation flow of cycle lanes and delays of cyclists at traffic signals. This in turn can help in designing cycle facilities at transport infrastructures. The validation of our investigation can also help transport planners with the calculation of the capacity, optimum width, comfort, and other operational costs of cycle lanes. Further work on this line of research will take care of the differences in the saturation flows between cycle-lane Tavistock Square and cycle-track Pocuro for each width and period of the day. In addition, other characteristics that affects the capacity of cycle lanes at traffic signals will be studied such as the gradient, turns to the right or left, behavior of cyclists and conflicts with pedestrians.

## References

- Akçelik, R., 1995. Traffic signals – capacity and timing analysis. Australian Road Research Board Ltd. Research Report 123, Sixth Reprint.
- Allen, D. P., Roupail, N., Hummer, J. E., and Milazzo, J. S., 1998. Operational Analysis of Uninterrupted Bicycle Facilities. Transportation Research Record 1636 (1), 29-36.
- Botma, H., 1995. Method to Determine Levels of Services for Bicycle Path and Pedestrian-Bicycle Paths. Transportation Research Record, (1502), 38-44.
- Brilon, W., 1994. A New German Highway Capacity Manual. In Proceeding of 2nd International Symposium on Highway Capacity, Vol.1, Sydney, Australia.
- HCM, 2000. Highway Capacity Manual, Chapter 11 Pedestrian and Bicycle Concepts. Transportation Research Board, Washington, D.C.
- Miller, R., Ramey, M., 1975. Width Requirements for Bikeways: A Level of Service Approach. Report 75-4, Department of Civil Engineering, University of California, Davis.
- MINVU, 2009. Recomendaciones para el Diseño de Elementos de Infraestructura Vial Urbana, REDEVU. Santiago de Chile. Retrieved 16th July 2014 in: [http://www.minvu.cl/opensite\\_20070404110715.aspx](http://www.minvu.cl/opensite_20070404110715.aspx)
- RRL, 1963. A method for measuring saturation flow at traffic signals. Road Note 34, Road Research Laboratory, Crowthorne.
- Stembord, H., 1991. Capacity Research and Applications: Country Report of the Netherlands. In Proceeding of International Symposium on Highway Capacity 1991, Rotterdam, Netherlands.
- TfL, 2011. Modal shares of daily journey stages in London. Transport for London, UK.
- Urbanism and Territory, 2013. Tacos de bicicletas llegan a Santiago: cuatro ciclovías están casi saturadas, La Tercera, Enero 31, p34, Santiago, Chile. Retrieved 18th March 2013 in: <http://diario.latercera.com/2013/01/31/01/contenido/santiago/32-128889-9-tacos-de-bicicletas-llegan-a-santiago-cuatro-ciclovias-estan-casi-saturadas.shtml>