UNDERSTANDING CYCLE FACILITIES DESIGN AND CYCLIST TRAFFIC IN SANTIAGO DE CHILE

Rodrigo Vega, Natan Waintrub, Markus Niehaus, Carolina Peña, Patricia Galilea

Departamento de Ingeniería de Transporte y Logística, Escuela de Ingeniería, Avenida Vicuña Mackena 4860, Macul, Santiago, 7820436, Chile.

ravega@uc.cl

ABSTRACT

In Chile, the supply of bicycle infrastructure is depends of each municipality, without a supra-government and/or unified mandatory standards. The objectives of the present research are estimate the performance of the cycle facilities intersections and understand the cyclist's traffic behaviour. In order to do this, we characterize the users in terms of movements, gender and usage of helmet, and measure the physical characteristics of the infrastructure. Then, we estimate the capacity of the infrastructure and indexes of its performance. Also, we use linear regression and queue theory to obtain the traffic parameters affected by the conditions of the area.

Keywords: cycle-path design, cycle-path's capacity estimation, linear regression

1. INTRODUCTION

During the last decade, Santiago de Chile has suffered a huge increment in its use, doubling cycling share in the transport modal split since a 2.1% in 2001 to an incipient 3.9% in 2012 (SECTRA, 2015). Hence, the public transport infrastructure defined for each mode is adapting in a way to serve all the modes sharing it. To design proper spaces defined for each mode we must understand which are the demand and capacities of each transport facility, relevant to create an adequate transport infrastructure for each mode, in a way it is secure and efficient for their users.

This way, there is a need to understand traffic parameters of bicycles as vehicles, which has also become relevant for the increasing processes of infrastructure redesign. Thereby, the different speeds, space, security, priority of movements, and demand concerns of each transport mode add complexity to the use of public spaces such as streets and avenues. Consequently, new types of integrated public spaces, where the available space is shared within different transport modes, expose the need of a new understanding on how they could work together.

In Santiago de Chile, the lack of a standardized guides and norms resulted in a huge variety of solution for cycle-path designs; every municipality has its own ways to design cycle-path on intersections and paths. As a result, cyclists encounter a disconnect network of cycle-path, with different qualities; for instance, some of them have appropriate design widths, while others present obstacles in the path (as trees), intermittent cycle-path at intersections, narrow cycle-path (as small as 90 cm), holes and stand out objects, among others.

Nevertheless, a main project carried by the central government, Bicentenary Cycleways Master Plan (Plan Maestro de Ciclorutas Bicentenario), defined all axes in Santiago that needed a cycle facility (Ciudad Viva & Interface for Cycling Expertise, 2010). Moreover, the State announced on 2014 an expansion in the network of 190 km for the whole country (Ministerio de Vivienda y Urbanismo, 2014); and also, launched a guide of design recommendations (Ministerio de Vivienda y Urbanismo, 2015). This is especially relevant in Santiago, where local government agencies (i.e. municipalities) can build cycle-path infrastructure as they wish, but lack the information, experience, and knowledge to do it properly considering the different contexts where each future cycle-path is located.

We will focus our study where the major number of conflicts happens in cycle-paths: intersections. For this, we will characterize five intersections involving different types of facilities (located on the roadways, sidewalks or parks) and one intersection without a cycle facility, used as control.

Above all, the variety of designs gives us an ideal test-bed for understanding a considerable range of traffic behaviour schemes in different cycle-path designs. In this panorama, the objectives of the present research are: (i) estimate the performance of the cycle facilities intersections and, (ii) understand the cyclist's traffic behaviour. In order to do this, we characterize the users in terms of movements, gender and usage of helmet, and measure the physical characteristics of the infrastructure. Then, we use a novel methodology to estimate the capacity of the infrastructure. Also, we calculate a wide variety of indexes of cycle facilities' performance. Moreover, we use linear regression and queue theory to obtain the traffic parameters affected by the conditions of the area.

It is expected that these methodologies and indicators may contribute in the assessment of new infrastructure, serving as a tool for urban planners to decide between different alternatives of cycle facilities. This is particularly relevant, because most studies related to the design of cycle-path and traffic behaviour are qualitative and lack a quantitative analysis. And also, most of them are related with the local successful experience developing this kind of infrastructure, but without a quantitative background.

The following article is organized as follows: section two explain how, why and which data was gathered; section three shows the characterization results for the selected cycle intersections; section four develop a methodology to estimate capacity of cycle facilities; section five proposes several indicators to estimate the performance; section six analyses the data bank and the models estimated and; section seven summaries main conclusions and future investigations.

2. CYCLIST DATA GATHERING

This study needed a disaggregated form of traffic flow account in intersections, so we videotaped cyclists to estimate their speed distribution. In order to characterize users and their behaviour we selected six intersections. For the selection of the six intersections of analysis, we reviewed the available data of cycle facilities in Santiago. Then, we proceeded with the fieldwork measurement.

2.1 Intersection selection

In order to select the six intersections for this study, we used the only quantitative source of information found (at September of 2014): a study carried out by the Consultant UYT for Chile’s transport planning agency (SECTRA, 2013). They used automatic counting devices for cyclists, which were placed in nine cycle facilities of Santiago. However, only a few of them continued counting until today and further disaggregated data remains private.

In order to select where to count, SECTRA (2013) proposed and implemented the following methodology: the first step is to list and map (in GIS) all the existing network of cycle facilities in Santiago and identify the most important axes of circulation. Then, select the most homogenous and representative segment in each axis and, finally, choose the point of each representative segment for counting (SECTRA, 2013). The intersections for the present research were selected close to some of these counting points. Not only because the latter methodology is considered suitable, but on the grounds that the combined data collected presents a chance to contrast and expand the analysis.

We selected three cycle-paths in order to have a variety in the sense of location and infrastructure designs: Vicuña Mackenna (on the sidewalk), Andrés Bello (on the Uruguay Park), and Santa Isabel (on the roadway). We also had to select a specific intersection within each cycle-path, so we chose the main signalized intersection nearest to flow counters. As a result, the intersection selected were Vicuña Mackenna with Gerónimo de Alderete, Andrés Bello with La Concepción, and Santa Isabel with Vicuña Mackenna.

Three additional intersections were chosen to refine and broaden the analysis: Pocuro with Ricardo Lyon, one of the first junctions between two cycle-paths in Santiago; and Rosas with

Teatinos, one of the first cycle facility of the new high standard defined by the local government. It is noteworthy that later on, both cases where added to the automatic counter sample by UYT in agreements with local governments.

Finally, it was considered appropriate to have a control point, without any type of cycle facility. The point selected for this purpose was Dominica with Purísima, chosen by its proximity to the end of the cycle path of Pío Nono (which is the same axis of Dominica, but with a different name in that segment), making more likely a cyclist flow (Figure 1).

2.2 Field work

Once the intersections for this research were selected, it was necessary to define a methodology for their characterization. The idea was to consider every factor that affects the performance of a cycle facility, both regarding infrastructure and users. Since we had the data of the bicycle flows (SECTRA, 2013), we gathered the same information, allowing us to validate and expand the data obtained using the methodology proposed by Pettinga et al. (2009), which consists in recording videos and counting the volume of bicycle traffic.

Figure 1. Santiago's cycle facilities and selected intersections

For the determination of cyclists' speed we used the information from the recorded videos as described in Waintrub et al. (2015). Each intersection was recorded during one hour in the morning rush time; where, according to the data of SECTRA (2013), occurs the maximum usage of cycle-paths (as with the motorized traffic). Additionally, because the interaction with other transport modes is critical at this time, it tends to be a concentration of conflicts too. The dates selected for the fieldwork were Tuesdays and Thursdays of November and December 2014, since these are peak days in terms of cycling flows of the week. All days chosen had similar weather conditions, being mostly clear, allowing us to discard this factor from the analysis.

Also, the videos recorded can be used to determinate the capacity of a cycle facility. This characteristic is considered fundamental and it was not possible to find a methodology to calculate it. During the research process, the only reference to its value came from the Highway Capacity Manual 2010 (Ryus, Vandehey, Elefteriadou, Dowling, & Ostrom, 2010), but its original source could not be established. So, this paper proposes a novel methodology for the calculation of the capacity of a cycle facility presented in section 4.

The factors considered to characterize cyclists were: cyclist's gender and use of helmet. Nevertheless, it is strongly recommended that age and load, as others characteristics that could be considered important, to be studied in future research.

Similarly, we characterized the physical parameters that define cycle facilities and their intersections: materiality, width per way, lateral clearance (distance of the nearest object higher than 20 centimetres), number of objects higher than 20 centimetres next to the cycle facility (separated into three groups: between 0 and 50 cm, between 50 and 100 cm and between 100 and 150 cm), number of objects higher than 120 centimetres next to the cycle facility, presence and type of physical segregation with the motorized traffic, presence of counter flow traffic, presence of cyclist signs, presence of parking places in the parallel street, presence of parking places in the crossing street, high of the ditch (if the cycle facility goes on the sidewalk), number of vertical discontinuities (like the pass from the sidewalk to the roadway), number of horizontal discontinuities (changes of the materiality), number and size of protuberant objects on the cycle facility and number and size of sunken objects on the cycle facility. All these factors were measured for each of the sections of each cycle facility.

Finally, we characterized each intersection according to the numbers of accidents and injured with data from CONASET (2015)

We selected these factors in order to calculate the Bicycle Level of Service (BLOS) and the Danish Bicycle Level of Service (D-BLOS). Heights' stratification is important because objects lower than 20 cm next to the cycle facility do not affect its use, and objects taller than 120 cm make a more significant effect because they hinder the vision. In the same sense, different distance of objects to the facility is expected to impact differently the user.

Table 1: Cycle-paths characteristics and cyclist social behaviour

Cycle-path	**Uruguay**		**Santa Isabel**		**Dominica**		**Vicuña Mackenna**		**Rosas**		**Pocuro**		**Lyon**	
location of the cycle-path	park		on roadwayt with physical segregation		street		sidewalk		on roadway with physical segregation		sidewalk		on roadway with physical segregation	
cycle-path characteristics														
material	gravel		asphalt		asphalt		asphalt		asphalt		asphalt		asphalt	
section	1	3	1	3	1	3	1	3	1	3	1	3	1	3
cyclist trajectory (meters)	10.43	12.29	13.09	10	11.05	8.55	21.6	16.46	10.07	9.09	10.4	17.22	11.47	7.69
degrees of slope, direction A	-0.83%	3.23%	1.33%	0%	-1.45%	-1.84%	-0.27%	0%	0.09%	0.62%	1.11%	2.68%	0.04%	-1.17%
degrees of slope, direction B	0.83%	-3.23%	-1.33%	0%	1.45%	1.84%	0.27%	0%	-0.09%	-0.62%	-1.11%	-2.68%	-0.04%	1.17%
cycle-path entrance width, direction A	2.98	1.47	1.17	1.22	8.05	7.6	1.97	1.7	2.4	2.43	0.7	0.75	2.59	2.57
cycle-path entrance width, direction B	1.52	2.05	1.25	1.21	8.25	7.6	1.78	1.97	2.48	2.33	0.77	2.02	2.6	2.63
cycle-path center width, both directions	4.98	3.08	1.15	1.22	8.15	7.6	1.8	1.99	2.37	2.38	0.735	2.01	2.595	2.6
cycle-path direction width for direction A	2.49	1.54	1.15	1.22	4.075	3.8	1.01	1.073	1.18	1.185	0.35	1.05	1.2975	1.3
cycle-path direction width for direction B	2.49	1.54			4.075	3.8	0.79	0.917	1.19	1.195	0.35	1.05	1.2975	1.3
physical segregation material			tack						mound	mound			mound	mound
distant counter-flow motorized vehicles, direction A	1	1	0	0	0	0	1	1	0	0	0	0	1	1
distant counter-flow motorized vehicles, direction B	0	0	-	-	0	0	0	0	0	0	1	1	0	0
one-way cycle-path	0	0	1	1	0	0	0	0	0	0	0	0	0	0
quantity of vertical objects, bigger than 1.2 meters, before the cycle-path entrance, direction A	1	0	2	0	0	0	0	2	1	2	0	0	0	0
quantity of vertical objects, bigger than 1.2 meters, before the cycle-path entrance, direction B	0	0	1	1	0	2	0	0	0	0	0	0	0	0
cyclist signs, direction A	1	1	0	0	0	0	0	1	1	1	1	0	1	0
cyclist signs, direction B	1	1	0	1	0	0	0	0	1	1	1	1	0	1
quantity of vertical discontinuities	1	3	0	3	0	2	1	2	0	1	1	1	0	0
quantity of horizontal discontinuities	2	2	0	3	0	0	1	1	0	0	2	2	0	0
quantity of parallel objects at less than 150 cm, direction A	2	4	1	5	2	2	1	5	2	4	2	3	3	3
quantity of parallel objects at less than 150 cm, direction B	3	1	0	0	2	2	4	0	0	0	2	6	0	0
cyclist social and behavior characteristics[1]														
cyclist flow between 8:00 to 9:00	813		715		222		174		467		1109		1109	
percentage of women	33%	33%	28%	28%	18%	18%	13%	13%	28%	28%	33%	33%	33%	33%
percentage of cyclist with helmet	83%	83%	91%	91%	80%	80%	44%	44%	74%	74%	79%	79%	79%	79%
cycle-path usage, if available	79%	79%	80%	80%	0%	0%	63%	63%	97%	97%	98%	98%	98%	98%
cycle-path usage	76%	76%	57%	57%	0%	0%	54%	54%	82%	82%	98%	98%	98%	98%
roadwayt usage	3%	3%	21%	21%	82%	82%	14%	14%	13%	13%	0%	0%	0%	0%
sidewalk usage	21%	21%	20%	20%	18%	18%	20%	20%	5%	5%	2%	2%	2%	2%
transit lanes usage	0%	0%	3%	3%	0%	0%	11%	11%	0%	0%	0%	0%	0%	0%

2.3 Video Recording

As it is proposed by Pettinga et al. (2009), the cyclist flows and movements along the cycle-paths in morning rush hour (i.e. between 8 to 9 am) were obtained from videotape. In order to determine a cyclist's speed, it was necessary to achieve a horizontal wide lateral view of the cycle facility. Because the streets that the cycle facility crosses are too wide, we used two cameras, one in each side. Each cycle-path was divided in three sections: arrival, crossing –the intersection- and leaving. Then, the time a cyclist took at each section was obtained through a video processing. Cyclist's times in a section where marked when a cyclist crossed the beginning of the section and when it crossed the end. The difference between both is the time cyclists spent in that section. This time is directly related with the cyclist characteristics and behaviour; however, assigning these values to each observation requires extra processing time and aggregated values where used.

In particular, it was marked differently when the cyclist was using any of their possible options (cycle-path, sidewalk or street, if available). It was also marked differently when a cyclist abandoned a section of the cycle-path different from the defined end of the section. That is, a cyclist leaves the cycle-path without crossing the intersection. Also, if cyclists integrate a section of the cycle-path different from defined beginning of the section, it was marked differently.

With the cyclist's time in a cycle-path section, speed is obtained as the quotient between the trajectory and time of the cyclist in that section. This trajectory was measured for every cycle-path section, along other characteristics. Each section was divided in three, lengthen as much as the video capture the whole cycle-path. Thus, sections lengths are between 7.5 to 20 meters.

However, information of cyclist's times is summited to some errors as consequence of the processing stage that should be considered. First, cyclists that abandon a cycle-path section misconfigure relative cyclist times in a section. If a group of cyclists are queuing for the green light, and the second cyclist abandons the queue, the processing method is not able to mark the time of this abandon. This generates a problem to calculate waiting time in a red light and speed of cyclists in that section, so this information was dropped. Also, we observed that some cyclists wait the green light some centimetres further the section limits. Hence, it was defined that cyclist's queue in a red light –to cross the intersection- where located at the limit of the cycle-path section or before.

The time mark of each cyclist over the cycle-path section limits was obtained manually. That is, each cyclist that crosses a section limit was marked with a crossing time. This was realized for each cyclist in each section, obtaining a data set of more than 12,000 times for the six cycle-paths –and one reference street- after more than 42 hours of processing time. An error could be due to the manual designation of the times each cyclist crosses any section limit; lags may exist between the moment the analyst mark the crossing of the cyclist and the actual cyclist crossing. Additionally, time values where approximated to the nearest second; thus an approximation error on the velocity may be found.

Moreover, and due the perspective between the nearest point and the farthest point of the intersection, a cyclist crossing far away the camera would be seen later than a cyclist crossing near the camera. Anyway, this is a problem for wide cycle-paths (just the reference street is wide enough); however, the problem was diminished with the construction of perspective lines to process the videos.

Also, the information of the time between the beginning and the end of the cycle-path section is not associated to a particular cyclist. Therefore, overtakes of cyclists during a section is not captured. Anyway, this is not relevant because the data of the time take to cross the section, in a global way, is independent of overtakes.

As showed before, sections are divided between before and after the crossing. The former velocities where left aside in this work, but represent an ideal data bank for waiting time studies. The latter information was used as velocities may vary between cycle-path designs. Besides, information about the crossing design was also left aside since there is a problem to match with the cyclist in the crossing section.

Moreover, the depuration of the data bank consisted on checking coherence of the data obtained. First, small velocities where dropped because they were related to cyclists that spent more time than necessary in the cycle-path section. From the videos, we could see that these particular cyclists waited too much time at the side of the cycle-path looking at their phones, inspecting their backpack, and others.

Finally, we ended with a data bank of more than 1900 observations of velocities for six cycle-path and the control street. Now, with this information and the cycle-path characteristics, we have sufficient data to understand the relation between design characteristics and cyclist velocities.

3. CHARACTERIZATION OF THE USAGE OF CYCLE FACILITIES

Intersection disaggregated cyclist movements and user description were analysed jointly with the available data. The first important thing to note is that in all selected points, and in Santiago in general, cycling is used as a commuting transport mode instead as a recreational activity. This fact is reinforced both by our observation of users in field work and by hourly counting in a month as showed in Figure 2 and 3 for Andrés Bello. Though it is located in a recreational park, its weekday flow average is 4,350 cyclists and in weekends is only 2,650 by November 2013 (SECTRA, 2013).

This usage of cycle-paths is confirmed by the last citywide origin-destination poll, where cycling is employed for commuting to work or study purposes by a 52% and 9% respectively contrasting to a 10% for recreational purposes (SECTRA, 2015).

The examination of data gathered is remarkable in terms of reinforcing the importance of designing good facilities. To give a context, Table 2 shows the compilation of traffic information of different vehicles and the number of accidents and injured, for each one of the selected intersections.

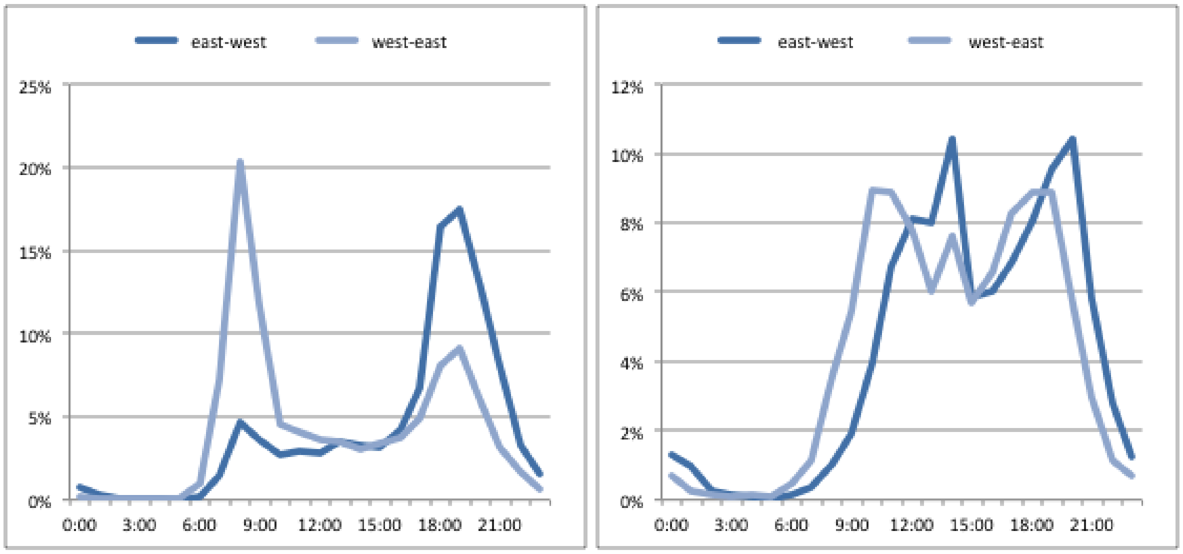

Figure 2 and 3. Average flow by hour proportion in Andrés Bello cycle-path.

Left: working day. Right: weekend (own elaboration based on SECTRA, 2013)

Table 2. Context information for selected intersections

	Andrés Bello	**Santa Isabel**	**Vicuña M.**	**Rosas**	**Lyon / Pocuro**	**Domi-nica**	**Total**
AM peak private vehicle arrivals[2]	6,518	5,279	3,551	2,112	2,305	1,629	21,394
AM peak transit vehicle arrivals[1]	0	1,070	1,551	225	0	210	3,056
Reported acci-dents (injured) [3]	8 (0)	8 (4)	7 (1)	0 (0)	5 (2)	0 (0)	28 (7)
Own measurements for cyclists							
8:00-9:00 arrivals	813	715	174	467	1,109	222	3,500
Avg. speed on cycle-paths by direction[4]	6.76 / 4.60	6.66	4.45 / 4.19	5.44 / 6.56	10.90* / 11.21*	8.4 / 6.24	6.73 / 8.37

---

[2] Estimated using ESTRAUS model for 2015 (SECTRA, 2009), unit in equivalent-vehicles per hour

[3] Based on police reports for year 2014, all accident types (CONASET, 2015)

[4] A result of the video records can be found in Waintrub *et al*. (2015). Note that it includes cyclists' speed both passing during green and accelerating after a red light. (*) Only for Lyon.

Note that Rosas and Dominica have no record of accidents at all, which should be treated with caution because it may be an actual misplacement of police reports. Also relevant is that all intersections have one cycle facility, except for Dominica with none (control) and Lyon/Pocuro which is junction of two.

Speed indicator in Lyon is by far the best, which is most likely related to its design. It is brand new and was the second among the new generation of cycle-paths called “high standard”, after Rosas. Both are on the street, wider than the rest and physically segregated by a proper buffer. Second best is the speed measured in Dominica at the roadway. Except for Santa Isabel, the rest of cycle-paths are located along with pedestrians, which explains the lower speed at intersections. Moreover, Santa Isabel measurement was located where the cycle facility ends and cyclists choose to continue on roadway or to cross with pedestrians. Therefore, these results tend to confirm that cycling may be faster in cycle-paths properly designed and segregated on the streets.

Further analysis is possible by observing the following figures, which confirms the latter appreciations on design now in a broader way by user preferences. Figure 4 displays where cyclists prefer to cycle for each intersection arrival. On most junctions the majority of cyclists tend to choose the dedicated infrastructure. Second by usage is roadway; however note that it is where cyclists are supposed to travel by law. Then, when the cycle infrastructure is designed along sidewalks, the authority is promoting a worse use of them at intersections. Moreover, Figure 5 specifically considers only the proportion of arrivals from movements that have cycle facilities. This indicator highlights the good design of Lyon and Rosas, and the latter also enhance a better usage of Pocuro’s cycle-path.

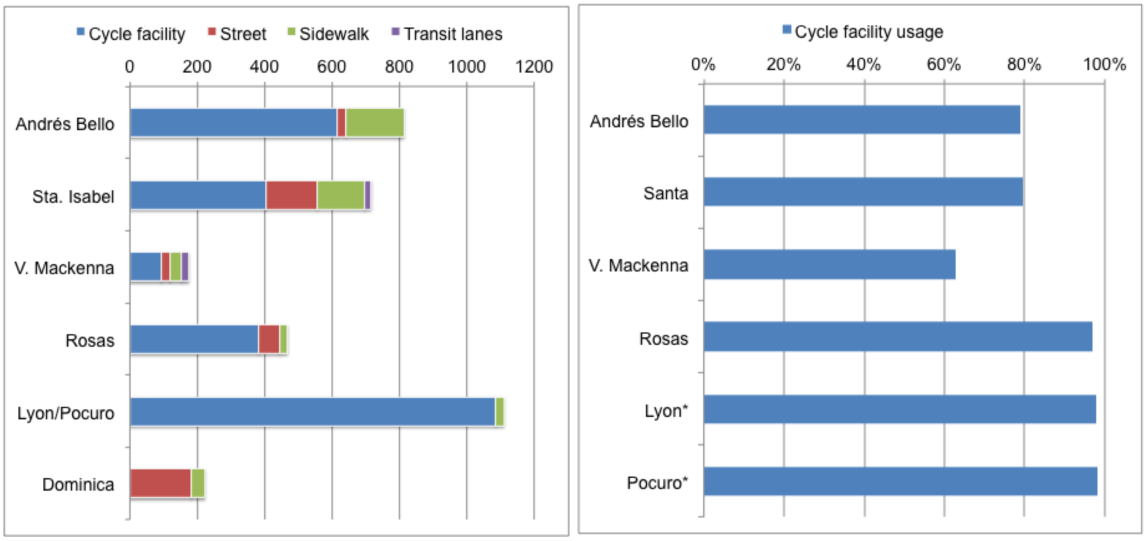

Figure 4. Cyclist arrivals by all movements – Figure 5. Cyclist facility usage

Along infrastructure use remains the characterization of those users. **¡Error! No se encuentra el origen de la referencia.**6 displays these indicators among the cyclist in each intersection for total arrivals.

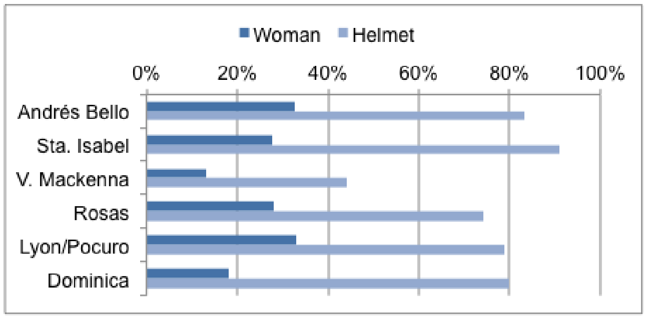

Figure 6. Presence of woman and use of helmet

These variations are related to the socio-cultural characteristics of the neighbourhood, but in similar ones it may talk about infrastructure design. For example, Vicuña Mackenna[5] (medium socioeconomic level) has a lower women presence and Pocuro (high socioeconomic level) gets a higher presence than supposed to be. This confirm the idea of Pettinga et al. (2009) that women are more likely to perceive the risks and to avoid them. Moreover, there may be a relationship between gender indicator and total cycling flows in each intersection, which can also be produced by the feeling of more safety in crowded places than in the lonely ones.

Anyway, woman indicator is worryingly low for the whole sample. In contrast, the case of the helmets is different as it is higher than expected with an average of 80.1%. They tend to be more used in high-income areas, which can be related to a knowledge and respect about the law (its use is mandatory) and/or to the capability to buy them, due to its cost can be prohibitive to the lowest income cyclists.

4. A METHODOLOGY FOR ESTIMATING CYCLE INFRASTRUCTURE CAPACITY

As far as we know, there is no published methodology for the determination of the capacity of a cycle facility. The only reference found to this fundamental factor was on the Highway Capacity Manual (Ryus et al., 2010, henceforth HCM2010), Volume 3, Chapter 18, page 71; where it is stated that the capacity can be as high as 2,600 bicycles per hour per lane, but it is recommended an average capacity of 2,000 bicycles per hour per lane, based on Opiela, Khasnabis, & Datta (1980). However, after reading that article, nothing was found about capacity in cycle facilities.

Therefore, we decided to determine this characteristic based on the data collected. Two different methods are proposed, depending on the behaviour observed on the different cycle facilities: we propose to use a Saturation Flow Rate for cycle facilities where cyclists do a queue while they wait for the green light and when the cyclists make a platoon when they wait for a green light we propose a Platoon's Capacity method.

---

[5] As it will discussed soon, Vicuña Mackenna's Cicle-path and Pocuro cycle-path have the same level of service (D-BLOS).

4.1 Saturation Flow Rate

When cyclists do a queue while they wait for the green light we propose to use a Saturation Flow Rate method. The hypothesis is that, in this situation, the behaviour is the same as that of the motorized vehicles (except motorcycles). Based on this assumption, the capacity can be obtained through the saturation flow rate (SFR) method, suggested by the HCM2010, which consist in recording the time of passage of the fourth and tenth vehicles in a queue during several traffic light cycles. The first three vehicles are excluded because of the transitory effect of reacting and accelerating at the start of the movement (Ryus et al., 2010).

In order to do this, it is necessary a line that has at least ten vehicles at the beginning of the green light. Nevertheless, it can be determined with fewer vehicles, but risking a greater error. Then, the saturation flow rate is calculated as follows (Ryus et al., 2010):

$$s = \frac{3600}{h} \tag{1.1}$$

with:

$$h = \frac{t_{10} - t_4}{6} \tag{1.2}$$

where s is the saturation flow rate, in vehicles per hour of green per lane; h is the average headway between the vehicles, in seconds; and t_4 and t_{10} are the average times passed since the start of the green until the pass of the fourth and tenth vehicles, in seconds, respectively. This method will be applied in the capacity calculated for the case of Andrés Bello and proportional to the width of the cycle lane.

4.2 Platoon's Capacity: TPC and CPC

The second method is for the cases where the cyclists make a platoon while they wait for the green light. In this situation, the behaviour is more like pedestrians, so the SFR cannot be applied. Instead, a new technique is proposed: the Platoon's Capacity (PC), which consists in recording the time of passage of every single bicycle in a platoon during several traffic light cycles.

As it happened with the SFR, it is expected that the first vehicles times are affected by reacting and accelerating times, so the hypothesis of removing it from the calculation process was tested. Moreover, it was observed that the vehicles at the end of the platoon also have a different behaviour than the ones in the middle, so they were treated as the ones in the front.

Additionally, we assumed that the group of vehicles at the centre of the platoon has an homogenous density and speed, and the size of the not-homogeneous borders are the also the same; both of which are the same in every platoon, independent of its size, as long as the width, slope, and materiality of the cycle path are equals.

We defined the average headway of a platoon as follows:

$$i_{ap} = \frac{t_f - t_l}{N_p} \tag{2.1}$$

where i_{ap} is the average headway between the vehicles in the platoon p, in seconds; t_f and t_l are the times passed since the start of the green until the pass of the first and last vehicles in the platoon, in seconds, respectively; and N_p is the number of vehicles in the platoon p.

If the total platoon is used for the analysis, the greater the number of cyclists, smaller the average headway, due to the larger proportion of the homogeneous part. Therefore, in order to create a mathematical model that describes the relationship between the number of cyclist and the average headway of a platoon, the functional form must be strictly decreasing and should converge asymptotically to the minimum possible headway, which will be called I_T.

Thus, the family of functions proposed for the calibration of this model is as follows:

$$i_{ap} = I_T + \sum_{j=1}^{J} \frac{\propto_j}{{N_p}^{\beta_j}} \tag{2.2}$$

where I_T is the minimum possible headway, in seconds; j is the indicator of the number elements of the function, from 1 to J; J, $\propto_j$ and β_j are the parameters of calibration of the model, whit J belonging to the Integers and $\propto_j$ and β_j belonging to the Positive Reals; N_p is the number of cyclist in the platoon p; and i_{ap} was previously defined.

Then, the capacity is calculated as follows:

$$TPC = \frac{3600}{I_T} \tag{2.3}$$

where TPC is the Total Platoon's Capacity, in vehicles per way per hour of green, and I_T was previously defined.

On the other hand, if just the central part of the platoon is used for the analysis, the average headway must remain constant, for every group. Therefore, in order to create a mathematical model that describes the relationship between the number of cyclists and the total time spent by the central portion of a platoon, the functional form must be strictly increasing and lineal, with intercept zero and a slope that will be called I_C.

Thus, the family of functions proposed for the calibration of this model is as follows:

$$T_{cp} = I_C \cdot N_{cp} \tag{3.1}$$

where T_{cp} is total time spent by the central part of the platoon p, in seconds; I_C is the average headway of the central part of the platoons, in seconds; and N_{cp} is the number of cyclist that compose the central part of the platoon p.

Then, the capacity is calculated as follows:

$$CPC = \frac{3600}{I_C} \tag{3.2}$$

where CPC is the Central Platoon's Capacity, in vehicles per way per hour of green, and I_C is the average headway of the central part of the platoons, in seconds.

4.3 Implementation in Andrés Bello cycle-path

Given that the cycle path of Andrés Bello is the one with the highest rate of platoon formation and with the largest size in the west to east way from the cycle facilities observed in Santiago, it was selected to test and calibrate the proposed methods. It is noteworthy that in future steps of this research, the test will be applied to all the others intersections of the sample, even the ones in where no platoon was created; in order to compare the TPC and CPC with the SFR.

To determinate the TPC, the i_{ap} was calculated for each of the 26 platoons registered during the one hour video recorded, for two different gantries: one in the waiting line of the intersection and one in the cycle path passed the junction.

Then, we calibrated the parameters J, $\propto_j$ and β_j using the software StataMP 13, which provides the capability to make linear regressions. However, the functional form is not lineal. This problem was solved by a previous elaboration of a set of $\frac{1}{{N_p}^{\beta_j}}$ terminus, which will be called x_{pj}. Then, the linear regression consists in:

$$i_{ap} = I_T + \sum_{j=1}^{J} \alpha_j \cdot x_{pj} \tag{4}$$

We should note that Stata can only do this process with a set of nine x_{pj}, all of them with different β_j integers from 1 to 9. Any additional terminus is considered collinear and omitted, regardless if they are integers or reals.

By the utilization of the t-test and the condition that every α_j must be positive, several of β_j were discarded and an analysis of the closest real number was made. The criterion for the selection of the real number was to maximize the r-squared value of the regression.

The best outcome for the cycle path estimated was $J = 1$ and $\beta_1 = 2.7$ obtaining an I_T of 0.9006 seconds (with a t-test value of 7.66), an $\propto_1$ of 37.5759 (with a t-test value of 2.36) and a r-squared of 0.1888. Although this value of r-squared is low, it is expected for small samples as ours. The resulting model is as follows:

$$i_{ap} = 0.9006 + \frac{37.5759}{{N_p}^{2.7}} \tag{5.1}$$

which is shown on the Figure 7, left. Therefore, the TPC is 3,997 bicycles per hour per way (b/h/w) in the cycle path downstream the intersection.

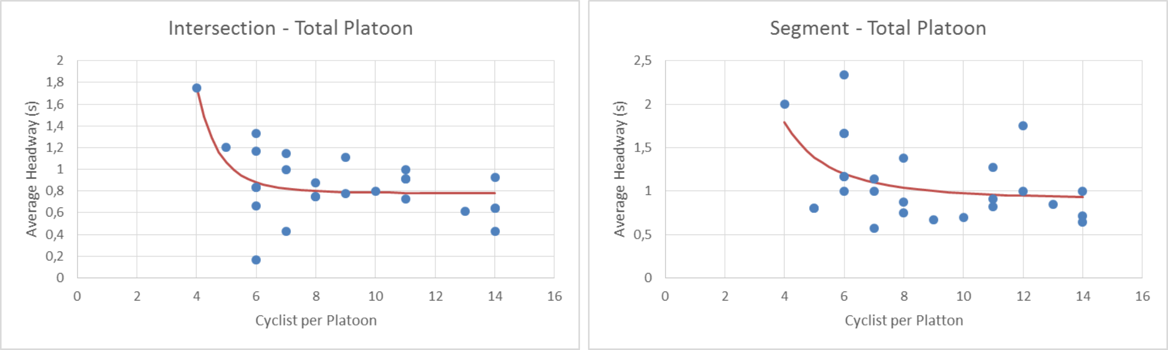

Figure 7 – TPC: observed (blue) and modelled (red).

The best outcome for the intersection estimated was $J = 1$ and $\beta_1 = 5.6$, obtaining an I_T of 0.7796 seconds (with a t-test value of 14.33), an $\propto_1$ of 2,324.138 (with a t-test value of 3.83) and a r-squared of 0.3788. Although this value of r-squared is low, it is expected for small samples as ours. The resulting model is as follows:

$$i_{ap} = 0.7796 + \frac{2324.138}{{N_p}^{5.6}} \qquad (5.2)$$

which is shown in the Figure 7, right. Therefore, the TPC is 4620 bicycles per hour of green per way (b/hg/w) in the intersection. Given that the green light for the cycle path is the 40% of the time, the TPC is 1848 b/h/w.

In order to determinate the CPC for the same two gantries, it was necessary to identify the homogenous part of the platoons. The first formula tested consists in the removal of the first two and the last two seconds of each platoon. This particular time (two seconds) was selected based on the typical reaction time suggested by the HCM2010 (Ryus et al., 2010), which applies on the first seconds and was extended to the last seconds for symmetry.

However, this procedure removes a different number of cyclists of each platoon, which leads to an uneven treatment. To avoid this problem, we decided to remove the first two and the last two cyclist of each platoon. This particular number was selected based on the average removed cyclists on each border by the first formula.

Then, we estimated the linear regression without constant with Stata for the cycle path. We obtained an I_C of 0.7809 seconds (with a t-test value of 15.1) and a r-squared of 0.9194. The resulting model is as follows:

$$T_{cp} = 0.7809 \cdot N_{cp} \qquad (6.1)$$

which is shown in the Figure 8, left. Therefore, the CPC is 4610 b/h/w in the cycle path downstream the intersection.

The same was done for the intersection, obtaining an I_C of 0.7515 seconds (with a t-test value of 13.44) and a r-squared of 0.9004. The resulting model is as follows:

$$T_{cp} = 0.7515 \cdot N_{cp} \tag{6.2}$$

which is shown in the Figure 8, right. Therefore, the CPC is 4790 b/hg/w in the intersection. Given that the green light for the cycle path is the 40% of the time, the CPC is 1916 b/h/w.

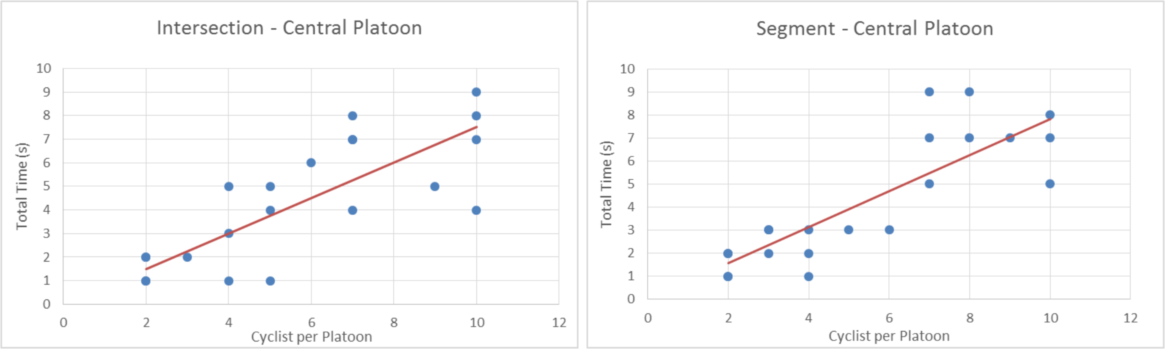

Figure 8 – CPC: observed (blue) and modelled (red).

4.4 Analysis of results

The difference between the results of the TPC and the CPC are of 13.3% and 3.6%, for the cycle path and the intersection, respectively. This difference could be due to the platoon behaviour happening just in the intersection, so these methods must be applied as close as possible to this point.

Moreover, given that the CPC models have a better r-squared value, is strongly recommended to prefer them over the TPC. Nevertheless, in order to use the CPC is necessary to successfully identify the homogenous part of the platoons. Probably, the number of cyclist that needs to be removed varies in each intersection, making impossible to extend the criteria used here to other junctions. Hence, it would be necessary to do that complex long task to each point of study.

On the other hand, despite that the TPC models have a worse r-squared value; the results that they produce are very similar to the ones from the CPC models. Therefore, if the homogenous central part of the platoons cannot be identified, it is strongly recommended to prefer the TPC over the CPC.

Also, it is noteworthy that the width of the gantry in the cycle path downstream the intersection is 1.52 meters per way, while on the intersection gantry is 2.05 meters. Thus, is reasonable that the capacity of the intersection per hour of green to be greater than the one of the cycle path, which has been proved.

The proportion between the TPC values and the width values differs by 16.8%, and the proportion between the CPC values and the width values differs by 29.8%. We believe that the difference of the first can be mostly explained by the fact that, despite that the intersection is wider, the space is not enough to reach two lanes, so the cyclist must to intercalate and cannot take complete advantage of the extra width. Besides, the higher difference of the CPC values and the width values is attributable to a not precise identification of the homogenous part of the platoon.

Furthermore, others factors can be intervening like the errors of the models, the materiality, and the slope.

Finally, we recommend the use of TPC method to estimate the capacity of this particular cycle facility. Then, the capacity of the intersection is the upper bound of the capacity of the whole facility with the actual green time proportion of 40%, being 1,848 b/h/w. However, the cycle path has a capacity of 3,997 b/h/w, which can be reached with a proportion of green time of 86.5%.

5. INDICATORS FOR CYCLE INFRASTRUCTURE ASSESSMENT

The results from this research encourage a proposal of useful indicators, whose analysis may help to plan and design better cycle infrastructure. In order to provide an adequate evaluation of the cycle facilities it is necessary to have comparable measures of performance. These results combined may suggest which designs are more suitable and also how cyclists could behave in them depending also in the area where cycle facilities will be constructed. From the last two sections, the following indicators are proposed and results are summarized in Table 3.

Table 3. Implementation of indicators for selected intersections with available data

	Formulae	**Andrés Bello**	**Santa Isabel**	**Vicuña M.**	**Rosas**	**Pocuro**	**Lyon**
Cycle facility capacity (b/h/w)	TPC[6]	1848	3461	3406	2655	783	5326
Cycle facility usage (%)	$\frac{Flow\ using\ cycle\ f.}{Movements\ with\ cycle\ f.}$	79.0	79.7	62.7	97.0	98.1	97.8
AM peak vs daily usage (%)[7]	$\frac{\sum_{workday} Peak\ flow}{\sum_{workday} Daily\ flow}$	12.3	11.4	7.2	9.4	-	-
Recreational index (%)[4]	$\frac{\sum_{t} Work\ day\ count}{\sum_{t} Weekend\ count}$	17.5	15.7	21.3	19.1	-	-
Cyclists resilience (%)[4]	$\frac{min(Monthly\ count)}{max(Monthly\ count)}$	67.1	-	-	-	-	-

Additionally, there are multiples alternatives in the literature, which include the BLOS (Bicycle Level of Service, Ryus et al., 2010), D-BLOS (Danish BLOS, Jensen, 2008), BEQI (Bicycle

---

[6] The formulae can be seen in the section 4.2. The value was calculated for Andrés Bello and extended to the others intersections proportionally to its width.

[7] Calculated from SECTRA (2013) and updated data given by UYT, but only for some data counters.

environmental Quality Index, San Francisco Department of Public Health, 2010), BRSI (Bicycle Route Safety Indices, Pettinga et al., 2009), BCI (Bicycle Compatibility Index, Pettinga et al., 2009), BRD (Bicycle Route Directness, Pettinga et al., 2009) and the WAC (Weighted Accident Count, Pettinga et al., 2009).

BEQI and BRSI cannot be calculated due to the lack of GIS data and more specific information about the accidents, respectively. However, it was possible to calculate the BLOS, D-BLOS, BCI, BRD and WAC[8]. Moreover, the D-BLOS was adjusted (henceforth, D-BLOS-A) to replicate the perception of the cyclist of the cycle-paths using the data of the survey made by SECTRA (2013).

The BLOS, D-BLOS and BCI try to evaluate the performance of the cycle facility as a whole, while the BRD and WAC are specific to the directness and accidents[9]. Also, the BLOS requires the delay at an intersection, which it is the expected wait of a cyclist given a certain ratio between flow and capacity and the percentage of green time (Bicycle Level of Service, Ryus et al., 2010).

Table 4 shows the BLOS, D-BLOS, D-BLOS-A, BCI, BRD and WAC for the selected intersections. As it was concluded by Parks et al. (2013), the BLOS is less sensitive to the specific characteristics of each cycle facility (gives an A for every intersection) than the D-BLOS, because it is focused on the motorized traffic. It is remarkable that even the BCI is more subtle, despite that the BLOS is its improved form.

Table 4 – BRD and WAC of the selected intersections.

	Andrés Bello	**Santa Isabel**	**Vicuña M.**	**Rosas**	**Pocuro**	**Lyon**	**Dominica**
BLOS	A	A	A	A	A	A	A
D-BLOS	A	F	B	A	B	A	D
D-BLOS-A	A	E	B	A	B	B	C
BCI	3.1	1.7	3.2	1.8	1.3	1.7	4.7
Delay A (s/b)	22.3	18.3	8.2	22.0	31.2	7.0	0.0
Delay B (s/b)	25.1	-	8.1	21.4	30.7	6.7	0.0
BRD	1.00	1.05	1.04	1.00	1.02	1.00	1.00
WAC	8	56	17	0	25		0

Andrés Bello has the best performance in all the indexes, altogether with Rosas, which just have a bad performance on the BCI. Despite Lyon has a similar design that the latter, its performance is worse, due to the higher motorized traffic on its side. On the other hand, Santa Isabel has the worst performance in all the indexes except BCI, where Pocuro is the worst.

---

[8] The motor vehicle's speeds and pedestrian flows could not be obtained and were treated as zero for all the intersections and indexes which were required. This will be corrected in future research.

[9] The data used was provided by CONASET (2015) and the factors are from Pettinga *et al*., 2009.

Dominica has a better performance than Santa Isabel, except in the BCI, regardless of not having a cycle facility. This shows how a bad specialized infrastructure is worse than no having infrastructure at all.

The delays are specified for each way of circulation (A or B), because they depend of its particular flow. Pocuro has the worst in both directions, due to its green time of only 33%, which also causes that Lyon has the best in both directions, because to its green time of 67%. Excluding Dominica, that has no delay given its not signalized, only Lyon and Vicuña Mackenna reach the desirable threshold of being less than ten seconds, while Pocuro is beyond the acceptable (Ryus et al., 2010).

In all cases the BRD has a value close to one, which means that all the cycle facilities are very direct. However, each intersection have very different WAC values, Santa Isabel being the worst, with 56, which means that is the most dangerous. This is probably related to the major motorized flow altogether with transit lanes, which implies a long crossing through heavy traffic.

Also, it is important to note that the WAC values for Pocuro and Lyon are just one, given that both cycle facilities cross in that intersection, but have different BRDs.

6. DATA BANK ANALYSIS AND MODELLING RESULTS

Before modelling the relations between cyclist velocities and cycle-path design, it is fundamental to understand and validate the data bank we are counting on. Hence, Table 5 exposes the average, maximum, and minimum velocities for each cycle-path studied.

Table 5: Cycle-paths speed statistics

	average		standard deviation		maximum		minimum	
direction	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Parque Uruguay	6.76	4.60	2.94	2.22	12.29	10.43	2.46	1.74
Santa Isabel	6.66	-	2.56	-	10.00	-	2.50	-
Dominica (control)	8.40	6.24	3.01	2.81	15.50	15.50	2.76	0.60
Vicuña Mackenna	4.45	4.19	2.28	1.56	16.46	7.20	2.35	0.54
Rosas	5.44	6.56	2.29	3.09	9.09	10.07	1.14	1.68
Lyon[10]	10.90	11.21	4.71	5.05	17.22	17.22	4.31	1.15
	6.73	8.37	3.01	4.87	17.22	17.22	1.14	0.54

With the average velocities of each cycle-path, we could observe a relation within the velocities and cycle-path direction; it seems that Dominica (control without cycle-path) and Lyon tend to be higher. Nevertheless, other cycle-paths on the roadway, Santa Isabel and Rosas cycle-paths, are

---

[10] For the case of Pocuro, the data was not accurate enough to determinate the speed, due to the problems mentioned before.

near the average speed and slower, respectively. Besides, maximum speeds are found in cycle-path on the roadway and the control street; consequently, these designs may be related to the fastest speed and other variables imply slower average speed (e.g. insecurity, bigger flows of cyclist, proximity to motorized vehicles). However, one of the cycle-path that exposes fastest speed is on the sidewalk (Vicuña Mackenna); but is also the street with the smaller flow of cyclists.

Also, on each cycle-path, one direction presents higher speed than the other. This could be related with cycle-path characteristics as flow behaviour. Respect the later, mass behaviour of cyclist may produce slower speed depending on the cycle-path widths or counter-flow that aloud overtakes. Since it is not possible to determine overtakes and characterize the mass of cyclist, it is left outside this study.

In addition to that, Table 6 exposes the relation of the average speed of cyclists with other variables. First, it is noticeable that the location of the street affects the cyclist speed differently; on the sidewalk and roadway tend to be fastest while on roadway, physically segregated, and the park are slower. This is counter intuitive, specially respect the on roadway cycle-path, but could be related to other factors as number of women on the cycle-path that tend to be slower; however, this could be consequence of a secure street and designed properly for all users, as its suggested by Pettinga et al. (2009).

Also, Table 6 shows some intuitive relations; cycle-path materials with higher friction, as gravel, are slower. Additionally cycle-paths with negative slope are faster for cyclist than those with positive slope, which require a bigger effort for cyclist. Moreover, if a cycle-path presents vertical discontinuities as sewage tap, high sidewalk difference with the street or big objects along the cycle-path, it shows smaller cyclists' speed. Finally, cyclist signs do not affect cyclists' speed and may have other effects; as demarcate to other street users the presence of a cycle-path (in case of share-street signs) or not relevant over the speed as cyclist traffic lights. Other interesting relationship is that distant motorized vehicle at counter flow are not affecting particularly cyclist's speed. This relation is intuitive, since cyclists going along with cars will be exposed to higher risk.

In contrast, some relations seem to be counter-intuitive. While cycle-path –and the control street-goes along without segregation with motorized vehicles, cyclist's speeds are slower compared to the speed of cyclist in cycle-paths over the sidewalk and park. Despite that, if the cycle-path is on the roadway and physically segregated, speeds are even slower than in the roadway without segregation with motorized vehicles. This may be consequence of the type of cyclist that goes along these cycle-paths, or even represent better cycle-path designs that allow the presence of slower cyclists.

Also, another interesting result is the percentage of women in the cycle-path. Considering cycle-paths with more percentage of women rises up to 32%, if women presence is higher than 25%, cyclist's speed appears to be higher. This is some way counter-intuitive, but it may represent other indirect effects. For instance, these same cycle-paths have higher flows at the time of recording and correspond to more secure cycle-paths; and finally, secure cycle-paths may expose higher velocities globally.

Table 6: Average and standard deviation speed related with cycle-path characteristics variables

	average	standard deviation
location of the cycle-path		
roadway	7.01	3.06
roadway, physically segregated	6.24	2.56
park	6.35	2.94
sidewalk	9.87	5.33
material		
asphalt	7.79	4.24
gravel	6.35	2.94
segregation respect motorized vehicles		
without segregation	6.87	2.87
physical segregation	5.59	2.44
sidewalk and park	8.20	4.71
slope		
negative	10.25	4.75
without slope	6.27	2.64
positive	6.20	2.97
percentage of women		
less than 25%	6.50	3.07
more than 25%	7.79	4.25
use of helmet		
less than 80%	8.09	4.53
more than 80%	6.47	2.80
horizontal discontinuities		
non existent	6.57	2.95
exist	7.85	4.36
vertical discontinuities		
not existent	9.45	4.76
exist	6.34	3.00
distance to motorized vehicles at counter-flow		
not distant	6.45	2.98
one cycle-path track	8.68	4.73
cyclist sings		
non existent	7.01	3.04
exist	7.71	4.49

Consequently, cycle-paths with less use of helmet have faster cyclists that one with more than 80% of cyclist helmet use. As the previous variable, this result may be related to the cycle-path design and security; the safest the cycle-path, the more cyclists feel they do not require protection accessories and show higher speeds.

Finally, cycle-paths with horizontal discontinuities seem to have a counter-intuitive relation; if they exist, higher speeds are found in the cycle-path. These discontinuities are related to changes in the street material, so its effects may be a consequence of how cyclists perceive these differences. They could see them as a secure path to increase speed, or just related to cycle-path that have presence of cyclist with higher speeds.

After this analysis, linear regression models (LRM) where calibrated. This approach is likewise the one used by Pettinga et al. (2009) with the Bicycle Compatibility Index (BCI) and Jensen (2008) with the Danish Bicycle Level of Service (D-BLOS), but using the speed as the explanatory variable instead of the quality of the cycle-path.

An initial model was estimated to find and drop observations with high leverage according to Cook test. From the initial data bank of 1923 observations, 95 of them correspond to observations dropped with the Cook test. Therefore, a data bank of 1828 observations was used for the final model.

Table 7: Estimated model with speed as explanatory variable

	Coefficient	**t-test**
location of the cycle-path - sidewalk	-2.81	-6.21
location of the cycle-path - park	-5.38	-7.17
location of the cycle-path - on roadway physically segregated	-4.70	-7.19
more than 25% women	4.76	9.61
distant counter-flow motorized vehicles	1.65	5.23
slope[11]	-0.89	-6.57
existence of vertical discontinuities	-0.94	-3.22
constant	7.36	37.05
Number of observations	1828	
R^2	0.3737	
$\overline{R^2}$	0.3713	

---

[11] Variable that takes the value of 1 if positive, -1 if negative and cero in other cases

A final model was obtained with a backward selection of the variables. It was checked the variables stability over the models and their t-test, with a level of confidence of 95%. The final model is showed in Table 7.

The $\overline{R^2}$ of the model seems relevant compared to all the models tried, with a similar value. Also, all variables are statistically significant and with the expected sign. In particular, a dummy variable was related with the location of cycle-path. In order of fastest to slowest cycle-paths design, the control street is the fastest, followed by the sidewalk, roadway with physical segregation with motorized vehicles and park. This makes sense considering the data set available, where fastest cyclist where observed in those cycle-paths.

Also, a cycle-path with presence of more than 25% of women is a faster street. This is illogical if related with a major presence of women, that tend to be slower cyclist; but it could be related to safest street, accordingly to the idea of Pettinga et al. (2009) that women are more likely to perceive the risks and to avoid them. Also, these cycle-paths may be ideal, due its design conditions, for cyclist to reach higher velocities.

In terms of sharing streets, cyclists that are in counter-flow and at least one path away from motorized vehicles are faster than cyclists at the side of them. This gives some light respect the importance of this characteristic. We modelled the effect of physical segregation with respect to motorized vehicles; the relation was positive (higher velocities if exists), but not significant. However, it does not mean that physical segregation is not important, since its results may be related to the fact that the chosen cycle-paths do not represent the real effect.

With respect to physical design, if the cycle-path has vertical discontinuities and positive slope, speed should decrease. The former is related to the ease of movement of cyclists along the cycle-path; if the path is continuous, speed is not affected. The latter is related with the difficulty of movement along the cycle-path. Positive slope means that cyclists are going upwards, requiring an extra effort to advance.

Now, in terms of social evaluation, the model could be used, in a preliminary stage, to estimate some cycle-path designs and the speed of cyclist to, finally, obtain some time savings due the cycle-path. For example, as pointed in Table 8, we could consider the velocities of Parque Uruguay cycle-path, improve the cycle-path and obtain the new velocities. In this case, fixing the vertical discontinuities of the cycle-path for each direction, we obtain an improvement of 69 and 87 seconds in one kilometre of cycle-path. Converting this in social values, this improvement generates annual savings of 7,200,214 US$.

Table 8 shows the savings if Vicuña Mackenna cycle-path is changed from the sidewalk to the roadway with physical segregation and an improvement in its security, increasing –accordingly- the number of women using the cycle-path in proportion. With this improvement, social annual savings are of 5,418,175 US$.

Table 8: Estimated annual savings[12] with cycle-path improvements

	Parque Uruguay		*Vicuña Mackenna*	
	direction A	**direction B**	**direction A**	**direction B**
observed velocity	6.76	4.60	4.45	4.19
modeled velocities with improvements	7.50	6.74	8.18	7.42
time difference in the intersection, seconds	2.1	9.9	22.1	22.4
subjective travel time value (MDS, 2015) US$/hour	2.34	2.34	2.34	2.34
average monthly flow – working days	39,559	42,452	13,081	11,700
average monthly flow – weekends[13]	7,488	9,989	3,809	2,888
savings for working days - monthly	$54	$275	$189	$171
savings for weekends - monthly	$10	$61	$52	$40
savings for working days - annually	$650	$3.298	$2.263	$2.052
savings for weekends - annually	$117	$735	$624	$480
annual savings per intersection (USD)	**$4.800**		**$5.418**	

Finally, these values could be used for evaluating a cycle-path. For example, if the government is planning to construct a new cycle-path, it could test the design of it and the flow to estimate – roughly- the savings in subjective time values. Also, it could be used to estimate how much will cost to fix the actual cycle-path in Santiago that are far away from the standards of a good cycle-path.

7. CONCLUSIONS

This research is a work in progress and its conclusions are limited to the selected intersections. Nevertheless, we will highlight the most important conclusions and recommend possible policy measures and future research.

The first important thought is to plan cycle networks more than to build stand-alone cycle infrastructure. Though Lyon and Pocuro cycle intersection design is not so coherent and is in a residential neighbourhood, the effect of both combined is strong in terms of arrivals and flows. Even if one is on the sidewalk and the other on the roadway, the cyclists tend to make a better use of both. Moreover, this improvement in placement of flows provides benefit for all modes in the junction, especially pedestrians.

Additionally, the relevance of good design itself is highlighted very clearly. The preliminary results for this specific sample of intersections conclude that physically segregated bike lanes on roadways are remarkably better. Both accounting level of service and how specifically cyclists

---

[12] Subjective travel time values for recreation and sport US$ 2.22 per hour (Ministerio de Desarrollo Social, 2015).

[13] Values obtained from SECTRA (2013).

use the infrastructure. Also, no cycle facility may be better than a bad cycle facility. This must encourage planners and authorities to achieve suitable cycle-paths and make a more efficient use of their scarce resources.

From latter outcomes it can be deducted some thoughts about safety. A coherent cycle network with better designs may reduce accidents related to cyclists in the medium term. However, to reach this conclusion an ex-ante and ex-post analysis is needed.

In the same manner, it is needed a cross-year analysis to confirm if better designs are promoting more women to cycle and a wider cross-design analysis to confirm if areas with higher socioeconomic levels do the same. Though a clear conclusion is that, unfortunately, cycling in Santiago is still more a manly mode of transport. Regarding helmets, the majority of the population uses them, but it may be less employed in low-income areas. Because of this, enforcing the people to use by paying tickets (as some have proposed) may heavily affect the more vulnerable users.

The novel methodology of the TPC and CPC models results in reasonable estimations of the capacity of a cycle facility. Then, they can be calibrated and used to calculate this fundamental factor to any infrastructure that allows the formation of platoons, even for pedestrians. This essential characteristic should be considered in order to build cyclist and pedestrian infrastructure capable to response to the demand, as it have been done with the motorized traffic.

The models of the relations between cyclist velocities and cycle-path design and users obtained in this work allow us to analyse the effect of cycle-path characteristics and user's characteristics with the estimation of models accordingly. In general, the results expose difference between different cycle-path designs, where the most relevant are the location of the cycle-paths, their relations with motorized vehicles and cycle-paths' irregularities as slope and discontinuities.

With these preliminary results, we estimated total savings with a change in the cycle-path design in terms of cyclist time. Later, and considering the subjective travel time values, adjusted for 2015, we obtained money savings for different cycle-path designs in Santiago. For example, in Parque Uruguay's cycle-path, an increase in 15% of the cyclist speed is due to the elimination of vertical discontinuities. Consequently, it results in a total of 7,200,214 US$ annual savings. Additionally, these results may be used to estimate total savings between designs in forthcoming cycle-paths in Santiago. Moreover, it could be used in a design stage of social evaluation projects to test different design and its effects final effects.

However, we need to include data that was left aside and obtain the annual savings within a range of possible values. In particular, we want to add the information of cyclists that are in a cycle-path section that could be affected by waiting time of the traffic lights, but they were not considered due the possibility they wait the traffic light to change. Also, we expect to include more information about the traffic behaviour of related motorized vehicles; nevertheless, we expect that values should not change considerably in cycle-paths located away from the vehicles lines.

In future studies, we will try to understand the diversified group characteristics' movement patterns in shared streets with infrastructure for private and public transport. Also, the indexes already calculated will be analysed to understand design factors that influence the dynamics of individual group movements, exposing relevant design criteria for the intersections in shared streets and translating them into indicators that could be used in social evaluation scheme for future cycle-paths and as a guidelines for the development of new infrastructure.

ACKNOWLEDGEMENTS

We want to thank Hernán Silva and UYT for providing some of the data from automatic counters of cyclists. Also, we gratefully acknowledge the research support provided by the Centre for Sustainable Urban Development (CEDEUS, CONICYT/FONDAP/15110020) and the Bus Rapid Transit (ALC-BRT) Centre of Excellence funded by the Volvo Research and Educational Foundations (VREF).

REFERENCES

Ciudad Viva, Interface for Cycling Expertise, 2010. El Plan Maestro de Ciclo Rutas del Bicentenario, 58.

CONASET, 2015. Personal communication by e-mail.

Jensen, S. U., 2008. Pedestrian and Bicyclist Level of Service on Roadway Segments. Transportation Research Record: Journal of the Transportation Research Board, 2031, pp. 43–51. http://doi.org/10.3141/2031-06

Ministerio de Desarrollo Social (Marzo, 2015). Precios Sociales Vigentes 2015

Ministerior de Vivienda y Urbanismo. (2014). Presidenta Bachelet anunció Plan de Áreas Verdes y construcción de 190 kms de ciclovías de alto estándar en todo Chile. http://www.minvu.cl/opensite_det_20140517155301.aspx

Ministerio de Vivienda y Urbanismo, 2015. Manual Vialidad Ciclo Inclusiva - Recomendaciones de diseño.

Opiela, K. S., Khasnabis, S., Datta, T. K., 1980. Determination of the characteristics of bicycle traffic at urban intersections. In 59th Annual Meeting of the Transportation Research Board Proceedings. Retrieved from http://trid.trb.org/view.aspx?id=160014

Parks, J., Tanaka, A., Ryus, P., Monsere, C. M., McNeil, N., Goodno, M., 2013. Assessment of Three Alternative Bicycle Infrastructure Quality-of-Service Metrics. Transportation Research Record: Journal of the Transportation Research Board, 2387, pp. 56–65. http://doi.org/10.3141/2387-07

Pettinga, A., Rouwette, A., Braakman, B., Pardo, C., Kuijper, D., de Jong, H., Godefrooij, T., 2009. Cycling-inclusive policy development: a handbook, Utrecht. Retrieved from http://trid.trb.org/view.aspx?id=1151924

Ryus, P., Vandehey, M., Elefteriadou, L., Dowling, R. G., Ostrom, B. K., 2010. Highway Capacity Manual 2010, TR News (273). Retrieved from http://trid.trb.org/view.aspx?id=1102481

SECTRA, 2009. Análisis y seguimiento de planes de desarrollo 2006-2012, OT 4. Report by CIS Asociados Consultores en Transporte S.A and Trasa Ingeniería Ltda, Santiago.

SECTRA, 2013. Análisis del comportamiento de la demanda de infraestructura especializada para bicicletas. Report by UYT Consultores, Santiago.

SECTRA, 2015. Encuesta Origen Destino de Viajes Santiago 2012. Report by Observatorio Social, Universidad Alberto Hurtado, Santiago.

San Francisco Department of Public Health, (2010). Bicycle Environmental Quality Index Survey, Program on Health, Equity, and S. U. H., & Place Team (June).