Traffic conflict analysis by an instrumented bicycle on cycle tracks of Valencia

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ABSTRACT

Bidirectional cycle tracks in Valencia (Spain) are usually placed between pedestrian sidewalk and motor vehicle parking. They are separated from the other users by a line, a line of trees, hedges or a curb. Bicyclists should yield to pedestrians at some points.

Using an instrumented bicycle provided with four cameras, four rangefinders, a laser pointer, a microphone and a GPS tracker, every conflict occurring with vehicles or pedestrians was analysed. The main Traffic Conflict Techniques (TCT) parameters such as Time to Collision (TTC), Conflicted Speed (CS) or Post Encroachment Time (PET) and a subjective risk perception for every conflict were obtained. Conflicts were classified as "static objects", "wrong circulations" (pedestrians or motorbikes circulating on the cycle track), and "crossings", which could be law-compliance or not, depending on the location. 650 conflicts (70% pedestrians) were studied in 6 different cycle tracks in Valencia. 10 hours of video were recorded on a 130 km stretch.

The study showed that is possible to detect conflicts (and to obtain the main TCT parameters) from a bicycle in movement allowing the researchers to create maps of conflicts and detection hotspots. The analysis compared each location by the number of conflicts per kilometre.

By studying the TCT parameters, a relation between TTC, CS and subjective risk perception was founded, but it was not with PET, mainly in bicycle-pedestrian crossing conflicts.

Keywords: Bicycle safety, Pedestrians, Conflicts, Instrumented bicycle.

1 INTRODUCTION

Urban areas account for 40% of road fatalities [1]. Although there has been a remarkable improvement in traffic safety in recent years, it has been focused on the safety of motor vehicles. However, 50% of the victims of urban road crashes are pedestrians or cyclists [2].

In general, bicyclists identify safety as one of their highest priorities in selecting bicycle routes. A common characteristic of countries with a high cycling mode share is the provision of cycle tracks (separated bicycle-ways along streets) on major routes. For this reason, physically separated bicycle paths have received increasing attention from researchers. Wardman et al. [3] forecasted that a completely segregated bicycle roadway would result in a 55% increase in bicycling. A survey conducted in Canada corroborated that physically separated pathways were preferred by cyclists and encouraged more cycling [4]. Another study in Canada reported that the injury risk of cycling on cycle tracks is less than cycling in streets [5].

There is a significant interaction between bicycles and others users. Intersections, pedestrian crossings and motor vehicle crossings represent potential conflict hotspots. Besides, depending on cycle track boundary characteristics, other users (mainly pedestrians) may occupy cycle tracks generating additional conflicts.

Several research studies are based on hospital or police records and statistics [6], which provided data from accidents, but no information about the conflicts that occur on a daily basis. Besides, these data was insufficient to compare different cycle tracks in the same city in order to find out where to improve the infrastructure.

To avoid this problem, some researchers approach the problem studying not accidents nor flows but conflicts. With respect of conflicts involving other users, van der Horst et al. [7] recently analysed conflicts between bicycles, mopeds and crossing pedestrians focusing the research on the conflicts. They installed video cameras at fixed locations to extract trajectories of cycle track users. The interaction with motor vehicles was not considered. In this study, conflicts were analysed using the DOCTOR method (Dutch Objective Conflict Technique for Operation and Research) which indicated that there is a relationship between some indicators (such as Time to Collision and Post-Encroachment Time), conflict severity and crashes [8]. The study of van der Horst et al. was limited, however, to two locations and did not consider neither segment data nor the effect of specific infrastructure factors. The study of relation between some indicators and the severity of a conflict is part of the so-called Traffic Conflict Techniques (TCT), which study not just the number of conflicts in a traffic lane but the severity of those conflicts. According to this, a lane with more and more severe conflicts would have more probabilities of having an accident and, therefore, casualties.

Other authors have used instrumented bicycles to observe the interaction between motor vehicles and bicycles, though usually in cycle tracks separated from the motor traffic just by a marking line. They used either a naturalistic procedure as Dozza and Werneke [9] or a quasi-naturalistic method as Chuang et al. [10]. Dozza and Werneke [9] analysed data from a naturalistic study involving 16 cyclists, 332 trips, 1,459 km and 114 h. The authors identified 63 critical events, using a trigger installed on the bicycle, personal interviews and kinematic triggers (identification of extreme values of acceleration rates). Authors selected a comparable number of baseline (not conflictive) events, to carry out an odds ratio analysis, to identify whether specific factors were more common among the critical events or not. However, this study did not consider geometrical characteristics of cycle tracks, since data was not concentrated in particular facilities. The causes of each critical event were analysed, resulting in a 29% of conflicts related to pedestrians, a 33% to motor vehicles and a 16% to other bicycles. Dozza and

Werneke [9] found a quite small sample of critical events, as they only focused on severe conflicts and even on a certain number of accidents.

However, most of research on cycle tracks were focused on the study of following and overtaking manoeuvres, for either safety or operational analyses. Manar and Desmarais [11] studied bicycle-following behaviour. They collected data in a controlled experiment installing GPS receivers in two bicycles. The bicycles ran on a 1.7 km, 1.5 m wide (each direction) exclusive off-street cycle track. A similar cycle track was monitored, observing 253 couples of leading and following bicycles using a video camera mounted on a mast. They adapted and calibrated existing car-following models based on the observations.

As demonstrated by some authors, instrumented bicycles facilitated collecting continuous data along segments, in contrast to fixed locations. Walker [12] and Chapman and Noyce [13] equipped bicycles with either laser or ultrasonic distance measurement devices to analyse the lateral spacing between bicycles and motor vehicles during overtaking manoeuvres on two-lane rural roads. Lee et al. [14] used a high-accuracy GPS tracker on an instrumented bicycle to analyse the minimum manoeuvring space and lateral clearance on a one-way cycle track.

Conflicts among bicycles, pedestrians and motor vehicles should be a critical issue to determine geometrical characteristics of two-way cycle tracks. Specifically, intersection design and boundary characteristics might be related with frequency and severity of conflicts. Besides, geographical factors are behind the strong differences in bicycle infrastructure and users' behaviour among countries. For these reason, this work explores macroscopic and microscopic data of conflicts on a wide sample of cycle tracks in Valencia (Spain).

2 OBJECTIVES

The aim of the study is to develop a methodology to observe and analyse data of conflicts on cycle tracks within urban areas. These data should show not just critical events occurred on the cycle track but a sample of all the events which may be considered as "conflicts" following the definition given by Hunter et al. in 1999 [15]. A conflict was defined as "an interaction between a bicycle and motor vehicle, pedestrian, or other bicycle such that at least one of the parties had to change speed or direction to avoid the other". Nevertheless, normal circulation manoeuvres among bicycles as following, passing or meeting manoeuvres will not be considered as conflicts.

The objectives can be summarized as follow:

- Develop a quasi-naturalistic methodology to observe conflicts in two-way cycle tracks, using an instrumented bicycle.
- Observe conflicts in a sample of six two-way cycle tracks in Valencia (Spain) with different conditions and boundary characteristics: fences, trees, bushes, curbs, etc.
- Describe the participation of other users in conflicts.
- Characterize cycle tracks in function of the number and perceived risk of the conflicts.
- Develop a system to detect possible hotspots where the cycle tracks need attention due to critical conflicts or conflicts accumulation.
- Obtain the main TCT parameters, such as Time To Collision (TTC), Post Encroachment Time (PET) or Conflict Speed (CS), and others obtained from the GPS or video to characterize each observed conflict.

3 METHODOLOGY

The following section describes the methodology to observe conflicts from an instrumented bicycle, including the equipment, data collection procedure and selected locations.

3.1 Classification of conflicts

The first problem in analysing traffic conflicts on a cycle track is classification. The method to classify those conflicts was based on the DOCTOR method (Dutch Objective Conflict Technique for Operation and Research) as used in previous research [7]. According to this, the following classification was established (Figure 1):

- Crossing: a bicycle, a pedestrian or a motor vehicle crosses the bicycle path perpendicularly, exiting at the opposite side.
- Circulation: a pedestrian walks (or motor vehicles drives) along a part of the cycle track.
- Static obstacle: parked cars, litter, stopped pedestrians or any other static object on the cycle track.

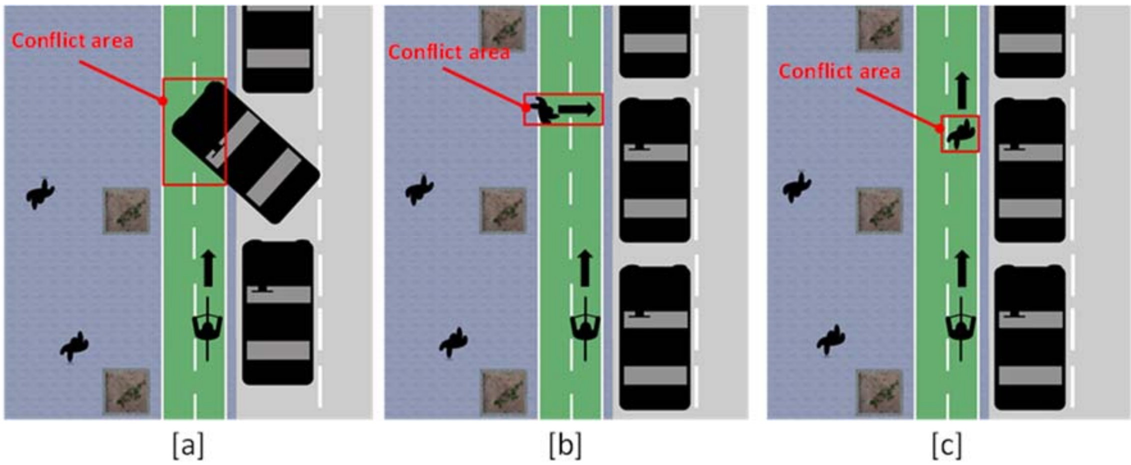

Figure 1. Classification of conflicts: static obstacles [a], crossings [b] and circulations [c]

While circulations and static objects were always a law noncompliance conflict, crossings could be law compliances or not depending on location. A pedestrian crossing the cycle track next to the instrumented bicycle is a law-compliance conflict if they are crossing through a pedestrian crossing but a noncompliance conflict if in any other place.

To avoid the effect of the instrumented bicycle riders' behaviour and facilitate data reduction, riders follow a pre-set behaviour (as explained below) and conflicts caused by the instrumented bicycle were discarded. Besides, conflicts associated with normal traffic conditions of cycle tracks (such as passing and meeting manoeuvres) were not analysed in this study.

3.2 Equipment

The bicycle had four video cameras installed ([a] in Figure 2) to record video information on the conflicts in which the instrumented bicycle was involved. A laser pointer [b] was used to help the bicycle riders to set their lateral position on the track, as well as to track this lateral position during data reduction. A 10 Hz GPS tracker [c] continuously registered position and speed of the instrumented bicycle allowing the researchers to obtain maps and exact information of every conflict spot. A microphone [d] was installed to register the rider's subjective risk perception to every conflict, based on a Likert scale from 1 to 5 (where 5 is the maximum risk perception and 1 the minimum). Video, audio and GPS position were stored in a VBOX data logger.

Two Laser Technology Inc. S200 rangefinders [e] measured the clearance between the bicycle and any crossing vehicle or obstacle in front of and behind the bicycle. A laptop connected to all laser devices stored the measurements. Additionally, two Laser Technology Inc. T100 laser systems [f] were installed perpendicular to the bicycle axis but their data was not used in this research.

In case pedestrians, vehicles or obstacles were not detected by front and rear laser rangefinders, a video mask was created to measure the distance to the bicycle (Figure 3).

Additionally, a trigger was installed, to be activated after every conflict to record the time the conflict took place.

All storing devices, batteries and accessories were installed in a box fixed to the bicycle frame. Cameras and laser rangefinders were placed in front and rear racks, adapted for this specific use. All the devices can be observed in the Figure 2.

Figure 2. Instrumented vehicle equipment

a: cameras
b: laser pointer
c: GPS
d: microphone
e: laser rangefinder S200
f: laserrangefinder T100

Figure 3. Video mask for distance measurements

3.3 Data collection

Data collection was conducted in six weekdays in April 2013 in sunny weather conditions and dry pavement. The data collection covered morning peak and non-peak periods in order to get various bicycle traffic conditions. During data collection, two cyclists rode the instrumented bicycle through a sample of two-way cycle tracks, riding round trips in natural conditions. The position adopted by the instrumented bicycle during the circulation was established in the centre of its lane of the cycle track. It was checked using a laser pointer, which was installed on the bicycle, pointing to the track centreline when cyclist was at the desired position. A camera recorded the position of the laser point in every moment to know if the bicycle was changing its position due to a conflict.

A sub-sample of cycle tracks was selected in order to measure the average free-flow speed of bicycles, using external static video cameras. A target speed was set accordingly, to ride the bicycle in a quasi-naturalistic way.

Using this methodology, two instrumented bicycle riders carried out round trips on the selected tracks, to observe a significant sample of conflicts.

Both riders performed naturally, although some rules were set to avoid the effect of individual's behaviour:

- Speed should be equal to 16 Km/h.
- Bicycle should ride at the centre of the proper lane.
- Traffic regulations and basic riding rules should be respected.
- Riders should not warn on upcoming conflicts by bell ringing, unless longer pedestrian circulation conflicts and risk for any user.

Lastly, after a conflict, the riders activated the trigger to register conflict time, and record their subjective conflict risk perception using the microphone. This variable was codified as a 1 to 5 Likert scale.

Conflicts associated with normal cycle traffic flow on the studied bidirectional cycle tracks (such as passing and meeting manoeuvres) were discarded in this research.

3.4 Locations

The study was conducted within the city of Valencia, Spain. Valencia has a 0.8 million inhabitants with a flat area of 134 square kilometres. Six two-way cycle tracks were selected. These six segments covered a wide range of cycle track width and diverse boundary characteristics. The analysed cycle tracks were bidirectional and separated from the motorized traffic in every case.

A variety of boundary characteristics was classified according to the following categories:

- None: absence of physical separation with pedestrian area (only marking).
- Bush: continuous obstacle to the handlebar height.
- Tree: discrete vertical obstacles, higher than cyclists.
- Parallel parking lane.
- Angled parking lane.
- Curb: continuous obstacle to the wheel height, it may be in presence of some of the other boundary conditions.

The selected locations and their characteristics are shown in the Table 1.

Location		Length (Km)	Location in cross-section	Width (m)	Boundary conditions
1	Tarongers (North)	1.530	Sidewalk	2.0	Bushes, trees
2	Tarongers (South)	1.530	Sidewalk	2.1	None, angled parking lane
3	Blasco Ibáñez	2.940	Sidewalk/roadway	2.0	Bushes, trees, angled parking lane, none
4	Port	2.520	Sidewalk	1.8	Trees, parallel parking lane
5	Peris i Valero	1.410	Sidewalk/Roadway	2.0 - 1.8	Trees and curb, parallel parking lane
6	Duc de Calabria	0.720	Sidewalk	1.5	Trees, parallel parking lane

Table 1. Characteristics of the analysed cycle tracks

3.5 Data reduction

Apart from audio and video data, 8 Hz-distance measurements and 10 Hz-GPS coordinates, as well as event data logging were stored during data collection. For each event (the rider activated the trigger after a conflict), a Visual Basic VBA algorithm looked for all the stored data in a time interval around it.

A more accurate conflict detection was carried out later, after individually revision of video, and rangefinder data. This facilitated the identification of conflicts, which were characterized by the following variables:

- Location (time and geographic coordinates).
- Type of conflicts (static object, crossing or circulation, as explained above).
- Second unit involved in the conflict (car, pedestrian, etc.).
- Subjective risk perception (1 to 5 scale).

- Boundary conditions, at the side from where the second unit entered the cycle track (based on previous classification).
- Specific cycle track element (pedestrian crossing, street crossing, none).

Where the conflict was a static obstacle, no more data was associated. For the other conflict types, a conflict zone was defined as the area where the trajectories of the instrumented bicycle and the second unit would have intersected, in case no evasive manoeuvre would have been performed.

Where the conflict was a crossing, the following parameters were also associated:

- Distance to the conflict zone, when the braking or an evasive manoeuvre began (Dbr) [m].
- Instrumented bicycle speed, when the braking or evasive manoeuvre began (Vbr) [Km/h].
- Sequence of bicycle and second unit (may be “after” – the bicycle passed after the second unit by the conflict area, or “before” – if the contrary occurred).
- Entrance/exit time (ENT, EXT) of the second unit in the cycle track (depending whether the bicycle passed before or after) [s].
- Time when instrumented bicycle entered the conflict zone (CZT) [s].

Where the conflict was circulation, the following data was also added to the database:

- Distance to conflict zone (pedestrian), when the braking or evasive manoeuvre began (Dbr) [m].
- Instrumented bicycle speed, when the braking or evasive manoeuvre began (Vbr) [Km/h].
- Time when the instrumented bicycle entered the conflict zone (CZT) [s].
- Bell-ringing time (Tbell) [s].
- Pedestrian/moped reaction time (PRT) [s].
- Time when the pedestrian/moped exit the cycle track (EXT) [s].

All the previous parameters where manually associated to every conflict from video data. The time needed to process manually the video data to obtain a database was around 2 h per hour of video. After that, another VBA algorithm calculated the following conflict parameters:

- Time to Collision at breaking time (TTCbr): TTCbr = 3.6·Dbr/Vbr [s]
- Post Encroachment Time (PET): PET = |EXT-CZT| [s]
- Conflict Speed (CS): CS = Vbr [Km/h]
- Reaction time (RT): RT = PRT – Tbell [s]
- Exit time (ET): ET = EXT – Tbell [s]

The total distance travelled by the instrumented bicycle, as well as travel speed in each location were also recorded. This was also carried out dividing the total data in segments with homogeneous boundary conditions.

3.5 Data analysis

Individual conflict records were aggregated in a database of 648 conflicts.

The analysis of these conflicts involved various steps. Firstly, a descriptive analysis showed the distribution of the sample of conflicts with respect of second unit type and risk perception (severity).

Later, the analysis focused on the frequency of conflicts on each cycle track. The distance travelled by the instrumented bicycle at each location were calculated. These distances were the base ratings to estimate the frequency of conflicts, and allowed the comparison between different cycle tracks.

After that, using the coordinates of the conflicts, their geographical distribution along cycle tracks was studied by using a geographical information system.

Lastly, the conflict parameters were calculated and statistical tests examined the relationship between them and conflict severity. The last step was centred mainly on crossing conflicts, the most severe and common conflicts. The analysis compared the severity index (as a factor) with objective indicators, such as TTC, PET or CS (as output variable), using ANOVA tests.

4 RESULTS

A total of 648 valid conflicts were obtained from more than 10 hours of video in a 130 Km. stretch. 124 static obstacles, 364 crossings and 160 circulations were analysed. This research carried out a descriptive analysis, to describe the observed sample. Later, the frequency of conflicts under different conditions was studied and the conflicts placed on a map. Next, subjective risk perception of severity and objective conflicts parameters were analysed. The analysis was mainly based on law non-compliance crossing and circulation conflicts though some subsections, as the study of conflicts with geographical information systems include every conflict detected.

4.1 Descriptive analysis

Pedestrians, bicycles and motor vehicles were considered as main conflict triggers, independently from the conflict type (static object, crossing or circulation). The results showed that pedestrian were the most common second unit type in the whole sample of conflicts, as seen in Figure 4. Pedestrian participated in 34% of static object conflicts, in 71% of crossings and in 91% of circulations.

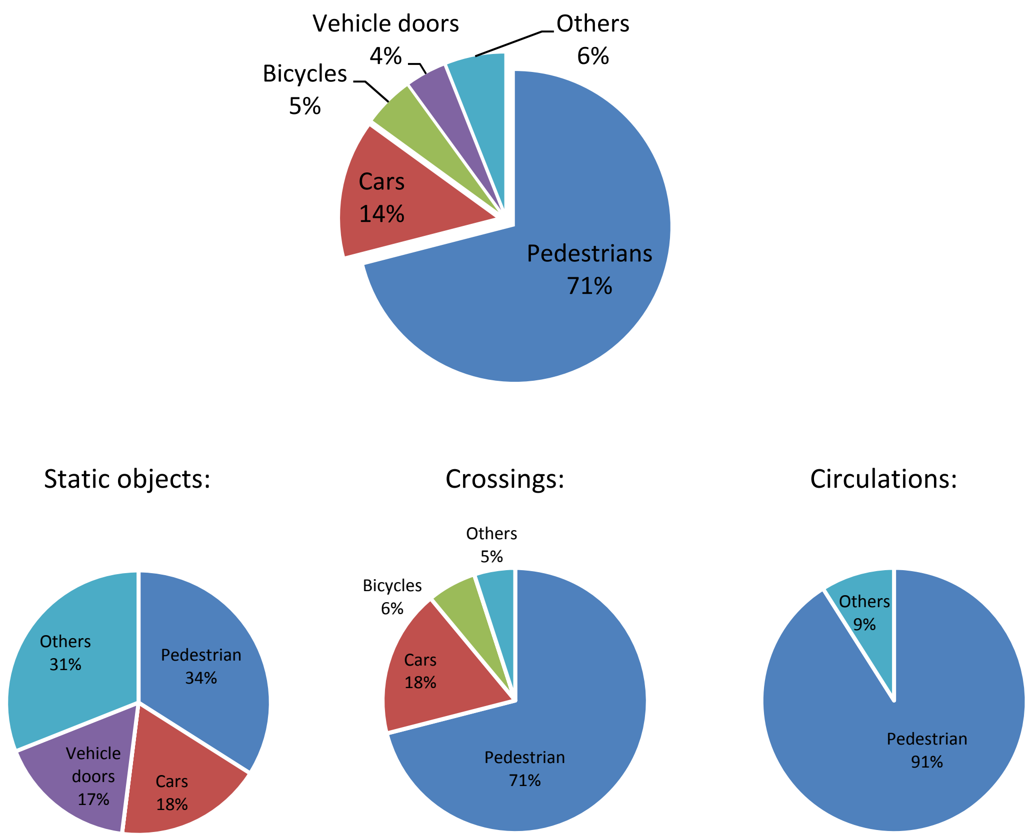

Figure 4. Sample composition, by second unit type and in function of conflict type

Besides, as the severity of each conflict was coded from 1 to 5 by the instrumented bicycle rider, the total number of conflicts per subjective risk level was also studied. The Traffic Conflict Techniques (TCT) describes theoretically a pyramid formed by the number of conflicts per level. This means number of conflicts should decrease with their severity following a second order function (assuming a square pyramid). Figure 5 shows this relationship.

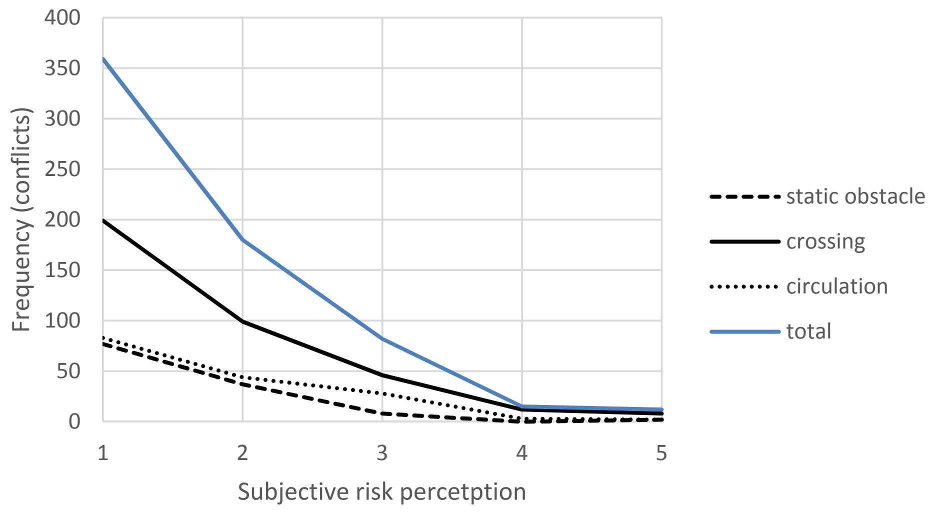

Figure 5. Subjective risk perception and frequency of conflicts

Figure 6 shows the relative frequency of conflicts by subjective risk category. In this figure, the percentage of static obstacle, crossings and circulations is shown for each risk level. While at lower severity perception levels, the number of static obstacles and circulation conflicts is still significant, with severe conflicts, most of observations were related to crossing conflicts.

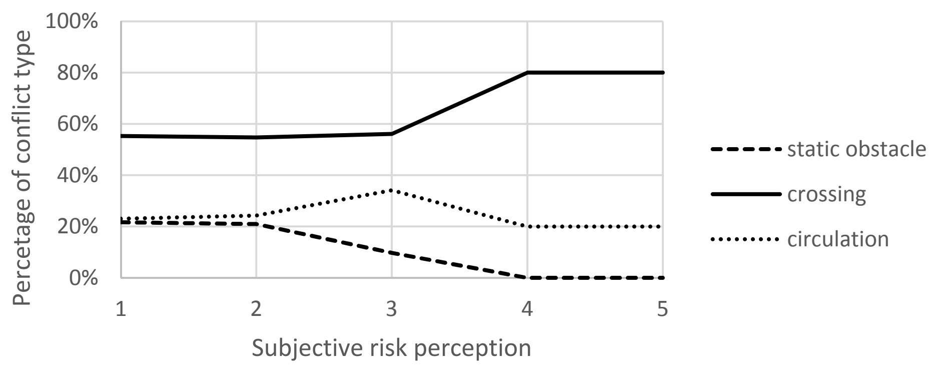

Figure 6. Percentage of conflict type by subjective risk category

4.2 Frequency of conflicts

The total number of conflicts per hour in each location was also calculated from the number of oncoming bicycles multiplied by two and the number of conflicts detected by the instrumented bicycle, using equation 1. This assumed that the instrumented bicycle collected average traffic data, which was reasonable taking into account the duration of data collection.

$$Frequency = \frac{Meeting\ bicyles \cdot 2 \cdot Observed\ conflicts}{Data\ collection\ time} \qquad \left(\frac{Conflicts}{h}\right) \qquad (1)$$

Table 2 shows the total number of conflicts per hour in each location. This table summarizes the number of conflicts than can be expected in each location. Without taking into account severity, the number of conflicts was very high in some locations, such as location 3 where, on average, more than 12,000 conflicts would take place in one hour.

Location		Meeting bicycles	Observed Conflicts	Data collection time (h)	Frequency (conflicts/h)	
					All	Severe (level 4 and 5)
1	Tarongers North	67	26	0.93	3,758	157
2	Tarongers South	60	96	1.54	7,479	312
3	Blasco Ibañez	70	140	1.54	12,658	527
4	Av. Del Port	69	154	2.13	9,964	415
5	Peris i Valero	51	114	1.74	6,673	278
6	Duc de Calabria	19	119	1.28	3,539	147

Table 2. Conflict frequency by location (including law compliance conflicts)

For the following analysis, only illegal conflicts were considered, meaning that a conflict caused by a pedestrian crossing on a pedestrian crossing was not taken into account. As the number of conflicts and time travelled in every location were known, conflict frequency (expressed in conflicts per km) was analysed.

Figure 7 shows a comparison of the six locations, based on the number of incorrect-behaviour conflicts per travelled kilometre. This allowed the identification of potentially dangerous boundary conditions. All locations had a significant number of crossing conflicts, while the number of circulations and static obstacles varied. In this figure, the lowest number of conflicts appeared in location 1 (Tarongers, North), where boundary conditions were classified as bushes and trees. The higher rate of conflicts were found at location 6 (Duc de Calabria), limited by trees and parking lanes.

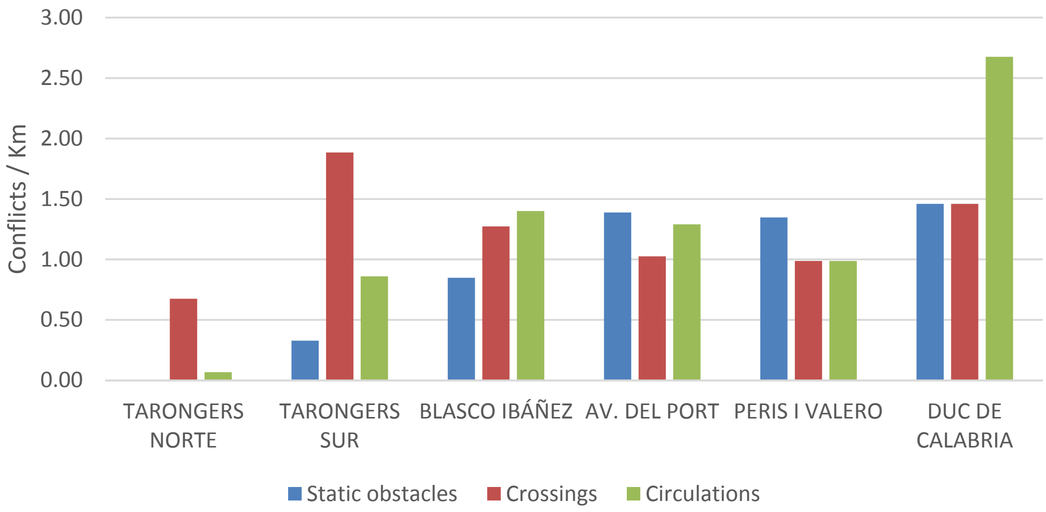

Figure 7. Conflict frequency by location

4.3 Study of the conflicts with geographical information systems

Each conflict has some associated data and data tables, containing all the information of the conflicts. With these tables, is easy to select a subgroup of conflicts to study them separately. With this system, we may (for example) select just the conflicts occurred on a particular location or with a particular second unit involved. With these tables, it was possible to select just the "crossings" were "pedestrians" were involved that occurred out of a "pedestrian crossing" or "street crossing", and the selected conflicts will be the law non-compliance crossings occurred on the cycle track were pedestrians were involved.

Using conflict geographic coordinates the conflict database was integrated in a GIS environment. In this case, mapping tools of Google Maps, Google Earth and Google Fusion Tables were used.

Consequently, it was easy to find the hotspots either by checking the places were the severe conflicts occurred or by checking the places where a large number of non-severe conflicts took place. A severe conflict is always a hotspot, neither an accumulation of non-severe ones, but in general, every hotspot is associated with at least one of these conditions. If conflicts were completely random, they would appear randomly distributed along the cycle track. On the contrary, the existence of hotspots reveals the influence of infrastructural factors.

As example, the process will be shown in just one location. Figure 8 shows three maps, which show the spots where static objects (white), crossings (red) and circulations (blue) occurred in Tarongers South.

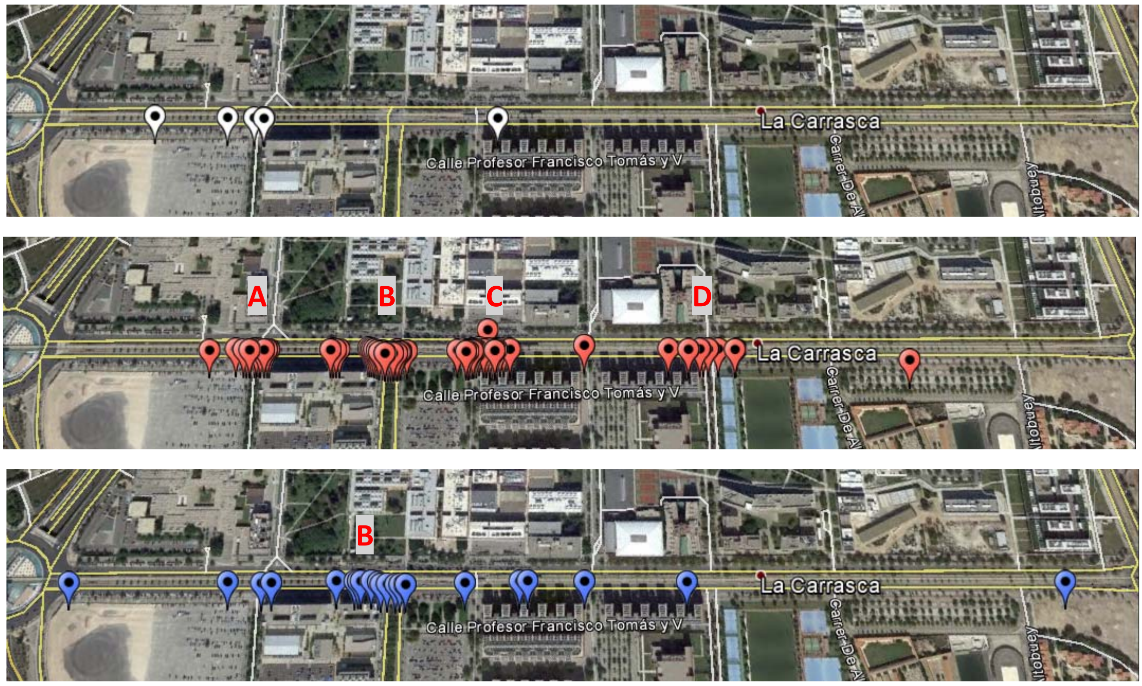

Figure 8. [a] Static objects (white), [b]crossings (red) and [c] circulations (blue) in Tarongers South

As seen in Figure 8a, the static objects were just 4 punctual objects with apparent no relation nor hotspot, so the analysis of the static objects ends here.

In Figure 8b, the crossings appear to mainly accumulate in four hotspots: A, B, C and D. All of them match up with pedestrian crosswalks, which are used by many university students. Pedestrian crosswalks are placed on the cycle track to ease the crossing of the street and cycle track, but many pedestrian take a shortcut by crossing the cycle track incorrectly as shown on the Figure 9.

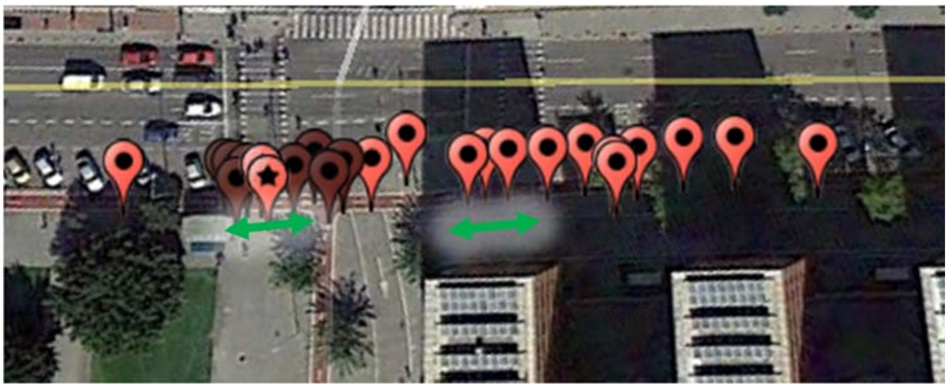

Figure 9. Crossings on the point C and pedestrians crossings (green)

The point B is a hotspot with both crossings and circulations, as shown on the Figure 10.

The junction of 3 pedestrian crosswalk next to a bus stop and a public bicycle station makes this point a clear hotspot (Figure 10) which should be improved in order to reduce the number of conflicts around the street crossing to avoid eventual accidents. Some of these cycle track improvements could be, among others: add pedestrian crossings, place bushes or fences where pedestrians should not cross, place the cycle lane at asphalt height instead of the sidewalk height..

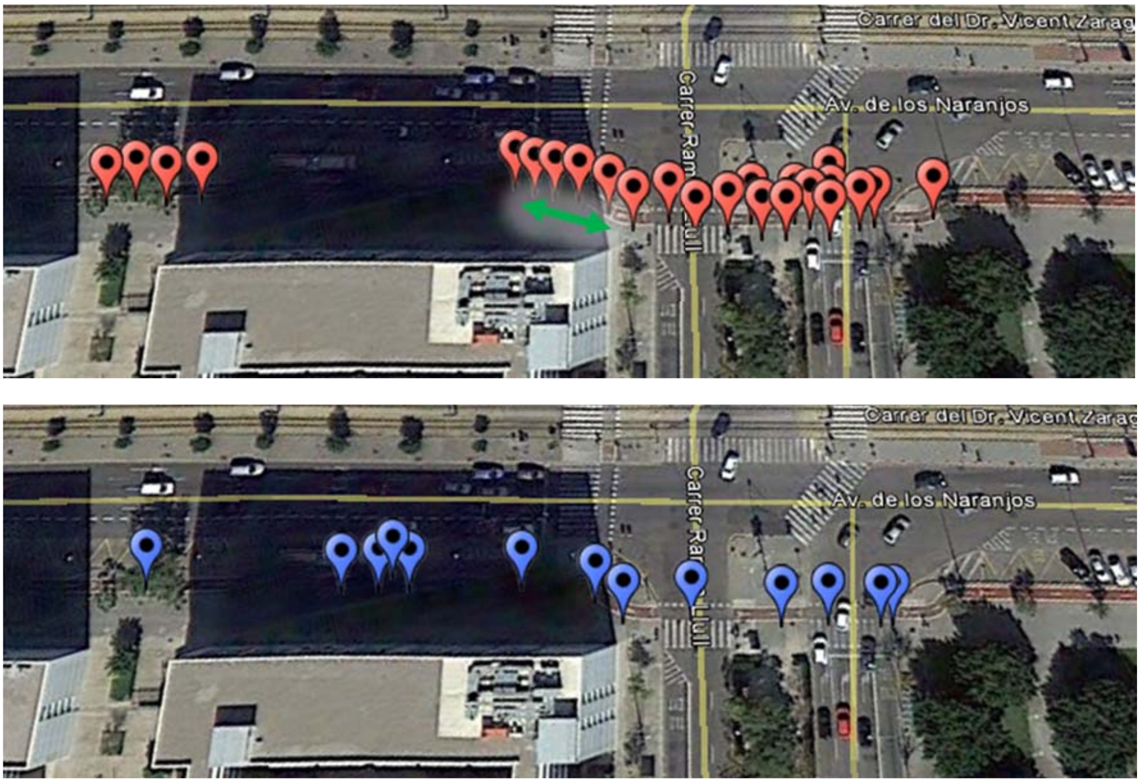

Figure 10. Crossings and circulations on the point B and pedestrian crossings (green)

The possibilities of a centralized large-scale map of conflicts have not been tested yet, as only a few locations and few hours were analysed. Nevertheless, it is clear that a bicycle in movement could create that map, aiding to detect the hotspots before a severe accident takes place on them by detecting the accumulation and severity of conflicts.

4.4 Conflict parameters and severity

The main traffic conflict parameters obtained in this research were Post Encroachment Time (PET), Time To Conflict at breaking time (TTC_{br}), Conflict Speed (CS) for crossing conflicts and CS, PET, Reaction time (RT) and Exit time (ET) for circulation conflicts. No analysis was applied to the study of static obstacle conflicts, due to a higher visibility and earlier perception, associated with lower severity levels.

The analysis of crossing conflicts showed that TTC_{br} came from lognormal distribution while PET and CS showed a normal distribution. It should be pointed out that CS showed an excessive asymmetry coefficient, although this result was caused by the selection of a target speed. Table 3 shows a summary of crossing conflict parameters. The three parameters were calculated for a sample of 364 conflicts (crossings conflicts).

Parameter	Mean	SD	Min	Max	Count	Distribution
PET (s)	1.5	1.0	<0.1	5.9	364	normal
TTC_{br} (s)	1.0	0.4	0.1	1,8	364	lognormal
CS (Km/h)	14.9	2.3	7.0	20.0	364	normal

Table 3. Conflict parameters for crossing conflicts

Strong differences were found between crossing conflicts in which the instrumented bicycle passed by the conflict area before and conflicts in which it passed after the second unit involved in the conflict. These differences appeared when comparing PET and TTC_{br} while CS did not show them (Figure 11). According to Figure 11, TTC_{br} was lower if the bicycle passed before, showing that the cyclist had less time to avoid the conflicts. However, PET was higher. This may be related to the fact that the pedestrian or vehicle stopped to let the bicycle pass by the conflict zone. Those differences were significant at the 95% confidence level (ANOVA test p-values < 0.005 in both cases).

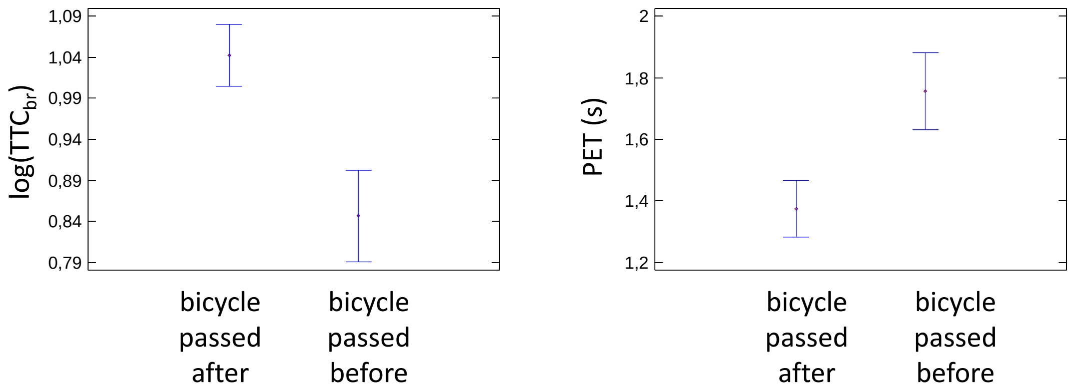

Figure 11. TTC and PET in function of sequence of instrumented bicycle and second unit in crossing conflict area

When the bicycle crossed the conflict area before the second unit, the values of conflict parameters were not related with the subjective risk perception as the ANOVA showed no coherent results. Nevertheless, the opposite occurred when the bicycle crossed the conflict area after the second unit. This may reflect that the user that crossed firstly the conflict zone was less aware of the conflict, compared to the second, which usually performs the evasive action.

Subjective risk perception of the driver was related, for cases of first arrival of the second unit, with TTC_{br} and PET. As seen in Figure 12, significant differences were found between subjective risk perception levels and the showed TCT parameters (ANOVA tests p-values < 0.005). Although CS showed also differences (increasing risk with CS), these were not as significant, maybe due to the selection of a target speed.

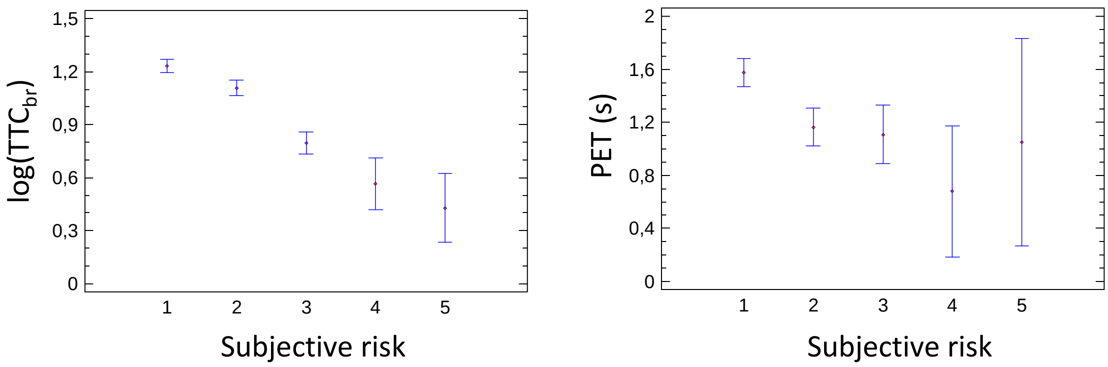

Figure 12. Relation between TTC_{br}, PET and Subjective risk perception

As seen in Figure 12, the relationship between subjective risk level and TTC_{br} was more statistically significant, being all risk level mean TTC_{br} statistically different form the other levels, except for 4 and 5. Less risky conflicts were related with TTC_{br} over 3 s (note the log-scale in figure), while the most dangerous events were characterized by TTC around 1.5 s. Although less significant, the same tendency was observer for PET.

With respect to circulation conflicts, Table 4 shows the different conflicts parameters. In this case, no correlation with severity has been found, being the conflict indicators unable to explain the severity of the conflict. Again, the better visibility of circulating pedestrians facilitated early detection. However, RT and ET provide information on the duration of the circulation and its effect to the normal traffic flow. On average, the reaction of the circulating pedestrian or moped occurred up to 1.9 s after bell ringing, and it left the cycle track on average 3.2 s after that. However, the reduced sample of this type of conflict made not possible additional analyses.

Parameter	Mean	SD	Min	Max	Count
PET (s)	0.4	0.6	0.0	2.3	160
CS (Km/h)	13.8	2.3	7.0	18.0	160
RT (s)	1.9	1.2	0.3	5.7	39
ET (s)	3.3.2	2.1	1.3	12.0	28

Table 4. Conflict parameters for circulation conflicts

5 DISCUSSION

Many studies have focused on the study of conflicts in general (quantitative analysis), or have tried to apply the Traffic Conflict Techniques (TCT) obtaining data from a particular intersection. This research has tried to obtain data from a full range of conflicts in long segments, relating this data with boundary conditions and with the main TCT parameters.

Among the main characteristics of this study, the high number of conflicts should be highlighted. This number is considered normal in cycle tracks on the sidewalk (not separated by anything but the pavement colour at some places) and when a minimum change of speed or direction is considered a slight conflict. This method has allowed the researchers to create interactive maps of conflicts of some locations in the city, to study the geographical distribution of conflicts and identify hotspots. The huge database let the researchers to just click on a conflict and access many indicators, from the subjective severity to the speed of the bicycle just before the braking manoeuvre (CS). The research have focused on two main areas. Firstly, a novel quantitative analysis of the frequency of conflicts by segments, streets or directly in maps (and their relations with boundary restrictions), And secondly, on the analysis of TCT parameters and their relation with the subjective severity, based on previous research [7].

With respect of the analysis on TCT parameters, a relevant relationship between subjective perceived risk and objective TCT parameters has been found. Hayvard [16] found firstly in 1972 a clear link among conflict types, minimum Time to Collission (TTC_{min}) and Conflict Speed (CS) for motor vehicle conflicts. Those results are comparable to the obtained in this research, though TTC at breaking time (TTC_{br}) was used instead of TTC_{min} due to the difficulty to detect it from a moving bicycle. However, this research demonstrated that even TTC_{br} had a good correlation with conflict subjective risk perception, especially for crossing conflicts.

Specifically, some methods, such as DOCTOR method, focused also in conflicts involving bicyclists. Van der Horst et al. [7] identified recently critical issues regarding bidirectional cycle tracks. They stated that the majority of severe conflicts (severity from 3 to 5, using the same scale as present work) were related to crossing conflicts. This agrees with present data, despite the higher differences in bicycle traffic volume (exceeding 1000 bicycles/h) and cycle track widths (3.5 m). The second most important type of conflict was the meeting manoeuvres. However, this conflict time was discarded from the present data as it corresponds to an additional part of the research [17].

Dozza and Werneke [9] proposed a different approach, based on large-scale naturalistic studies. Using this method, only 63 critical events were identified although 332 trips, covering 1,549 km were carried out. Despite the high volume and quality of naturalistic data, these researchers were unable to detect infrastructure geometrical factors, such as cycle track width or boundary conditions, because data was too disperse. Results, however, provided information about the second unit involved in each conflict: light vehicles participated in 30% of conflicts, pedestrian in 29%, and bicycles in 16%, being the rest heavy vehicles, animals, or other situations. While Dozza and Werneke [9] observed that pedestrians participated in only 29% of conflicts, this proportion was equal to 69% in the present study.

The comparison between previous research and the present results highlighted strong differences related to geographical factors. Either urban design or pedestrian and cycling behaviour is strongly dependent on the country were data is collected. The previous comparison showed differences in bicycle traffic volumes and in the participation of other users in conflicts. These conclusions suggested the necessity of analysing cycling data from different countries using the same experimental methods.

Lastly, in the same locations as the present study, Garcia et al. [17] showed how boundary conditions and track width affected conflictive meeting manoeuvres on bidirectional cycle tracks. That research was based in the same data set as the present study. While Garcia et al. demonstrated that cycle tracks without physical boundary conditions were more adequate to facilitate safe and comfortable meeting manoeuvres (especially if tracks were narrow), this study proved that on the same cycle track configurations, the frequency of conflicts related with pedestrians was much higher. The design of cycle tracks must take into account both issues, in order to achieve an adequate separation between bicycles and other users without affecting the interaction among bidirectional traffic flows. Nevertheless, is not possible to determine the degree of influence of the boundary conditions on the results. Some other factors, as the pedestrians traffic volume and others could affect the result given by a particular cycling track, and therefore affect the results regarding the boundary conditions, but this is an important point to study due to the importance of these boundary conditions, which separate bicycles from pedestrians and other vehicles in many cycle tracks.

6 CONCLUSSIONS

An instrumented bicycle has been successfully developed, to obtain data from conflicts. Apart from conflict frequency and video data, the main Traffic Conflict Techniques (TCT) parameters, such as Time to Conflict at breaking time (TTC_{br}), Conflict Speed (CS) and Post Encroachment Time (PET) were also determined.

The collection method was applied to six bidirectional separated cycle tracks in Valencia (Spain), which represented a sample of different geometries and boundary conditions. In order to observe conflicts on these cycle tracks, the instrumented bicycle rode along the tracks, carrying out successive round trips.

Researchers, in order to avoid undesirable effects and to obtain quasi-naturalistic observations, controlled data collection conditions. This was done by selecting a speed according to free flow cycle track users speed, and by riding centred on the right cycle track half. Conflicts caused by the instrumented bicycle riders were not considered.

A wide sample of 648 conflicts were analysed and classified as static objects, crossings or circulations. The analysis of these data provided the following results:

1. Among the total number of conflicts, the most common was the crossing conflict (56% of cases) involving a pedestrian or vehicle crossing the cycle track.
2. Pedestrians were involved in more than 70% of conflicts. This consequence might be associated with common cross-section design of urban streets in the analysed area, as most of cycle tracks are located on sidewalks, instead of roadways.
3. Crossing conflicts were perceived as the most risky, being almost that the only ones with a higher subjective risk perception.
4. In crossing conflicts affecting pedestrians, the following results were found:
    a. The sequence of bicycle and pedestrian affected the measured TTC_{br} and PET.
    b. If the pedestrian crossed the conflict area before the bicycle, the subjective risk perception decreased with TTC_{br}, PET and CS, being the relationship with TTC_{br} the most significant.

The main contribution of this paper was the development and testing of a new methodology to analyse traffic conflicts involving a bicycle and other users. The application of this methodology on cycle tracks described the characteristics of conflicts, in relation to the other users involved and the severity, measured from either a subjective or an objective point of view. Besides, this method was based on georeferenced data, which facilitated the creation of conflict maps and allowed the identification of hotspots. The analysis was limited, however, to a reduced sample of locations and conflicts, which made difficult the analysis of geometrical characteristic of cycle tracks and their potential influence on conflicts.

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