Mapping cyclist’s risk perception in an urban environment

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Abstract: Planning policies have evolved to increase cyclist's comfort and safety in the cycling infrastructure. However, the amount of information available regarding the cyclist’s risk perception and comfort according to the type of infrastructure in which they travel is very limited. Accordingly, the present research analyzed the risk perception of a group of 21 cyclists to identify if there was a common behavior of each group that could be used to categorize the type of infrastructure they traveled in. Prior to this analysis, each cyclist was classified in five different groups according to their comfort and level of cycling proficiency.The volunteers selected to take a part in the experiment were equipped with a device to measure biometrical parameters and another one to collect video and GPS data. From the collected data, we defined and applied a procedure to identify a set of events for each ride of all cyclist, related to their behavior. We also collected data on hindrances present on the infrastructure they travelled in, which could interfere with their cycling behavior. The biometric data was analyzed qualitatively, where a correspondence was searched between the moments of stress detected in those biometric registers and synchronized situations collected with video data, in order to identify possible differences of stress inducers among the various groups of cyclists. Our results suggest that there may be a correspondence between the driving behavior of a cyclist from a specific group and the characteristics that the roads in which they travel present.

Keywords: Comfort. Cycling infrastructure. Cyclist. Lisbon. Mapping risk. Video Detection.

1. Introduction

In recent years, there’s been an increase of the amount of planning polices with a particular emphasis in the use of cycling as a mean of transport in short and medium sized trips (less than 5 km), (Pucher and Buehler, 2008), where bikes can compete with motorized vehicles. (IMTT, 2011)

Due to the many benefits of bikes in terms of health and infrastructure congestion and costs associated, (Pucher and Buehler, 2017), there has been a significant increase in the length of dedicated bike networks and many bike sharing programs have been created. This measures have resulted in a significant growth of regular bike trips in urban areas, where Amsterdam and Copenhagen’s commuting bike shares can reach about 40% (Pucher and Buehler, 2008).

However, due to road carriage space and budget restrictions, it’s impossible for the cyclists to travel in dedicated facilities exclusively, meaning that some part of their trips will have to be made in a mixed traffic environment. These circumstances may hamper the growth of the cycling modal share, and for that reason there’s a need to measure the cyclists comfort and risk perception in those different situations, to help prioritize the bike infrastructure projects to be done and help cyclists making their route planning decisions before they initiate their trips.

The wealth of data related to risk regarding bike usage is very limited, where the existing information usually relates only to accidents reports and surveys and almost no concrete info regarding cyclist's risk perception.

Here, we provide a method to hierarchize the existing road and cycling network infrastructure based on the measured comfort of probe cyclists that are previously classified according to their cycling proficiency through a questionnaire.

We aim to prove two main hypotheses:

1. If we know the group to which a cyclist belongs, through its cycling behavior, we can identify the characteristic of the roads in which it travels.
2. If hypothesis number one is confirmed, we can extend the present analysis with probe cyclists mapping the characteristics of the infrastructure while they travel, cumulatively.

2. Review of Literature

Literature review is structured in four different parts: 1) classification of the infrastructure in terms of planning regulations, 2) classification of cyclists, 3) measurement of safety and comfort of cyclists in the cycling infrastructures and 4) use of technology in the analysis of cyclist's experience.

2.1. Classification of the infrastructure according to planning regulations

According to the Cycle Infrastructure Design (UK Department for Transport, 2008), three different distances need to be considered for cycling infrastructures: the dynamic envelope, which is the width cyclists need to circulate, defined as approximately 1 meter; the distance to fixed objects, defined in the Portuguese norms as 25-50 cm distance to the sidewalk, 5 cm to vertical signaling and public lights and 1 meter to facades (IMTT, 2011); and, also, the distance to moving objects from which a distance of 1-1,5 meters should be considered.

Besides the cyclist requirements for cycling safely and comfortably, the cycling infrastructure, including road infrastructures, should have comply to minimum standards to accommodate for safe circulation of cyclists.

(Austroads, 2014) defined five main conditions that highways should assure in order to be safe and comfortable for cyclists: 1) enough space for maneuvers and a low risk for the cyclist; 2) coherent network; 3) while ensuring adequate connectivity and continuity; 4) little braking and maneuvers should be required from cyclists; and 5), lastly, it should guarantee adequate attractiveness and directedness to reach the main destinations.

To satisfy these conditions a hierarchy of the planning decisions should be made sequentially. Priority is given to mixed traffic conditions, while adding traffic calming measures at the same time. Then, exclusive bikeways or bike paths should be built when mixed traffic conditions are not sufficient to accommodate cyclist safely. Ultimately, when no other solutions are possible, share pedestrian sidewalks with cyclists. (IMTT, 2011)

In short, cycling networks include three main bicycle infrastructures: 1) mixed lanes, in which motorized vehicles should travel at a lower speed and with lower traffic flows; 2) dedicated bike lanes separated from the motorized traffic by a line on the road pavement; and 3) cycle paths which are segregated from the road carriageway (IMTT, 2011). The criteria adopted to define what cycle infrastructure should be considered in every situation combines motorized traffic speed (average 85th percentile) and traffic flow conditions (NACTO, 2011)

2.2 Classification of cyclists

Cyclists can be classified according to characteristics of comfort, skill or experience.

In terms of comfort we have Geller's classification (Geller, 2006), which divides cyclists according to their tolerance in mixed traffic conditions. He identifies 4 different groups: 1) strong and fearless, 2) enthused and confident, 3) interested but concerned and 4) no way no how. Another classification based on skill divides the population of cyclists in three groups, Class A (Advanced cyclists), Class B (Basic cyclists) and Class C (Children). (NACTO, 2011)

Cyclist can also be classified based on their experience that they present, with three different categories: frequent cyclist, occasional cyclist and inexperienced cyclist. (IMTT, 2011)

2.3. Measurement of safety and comfort of cyclist for different cycling infrastructures

The evaluation of the safety and comfort of bike users can be defined in general terms by the term "Bikeability of the infrastructure" they use.

The first methods to evaluate infrastructure bikeability were based only on its design characteristics and road traffic usage, by defining *a priori* criteria of infrastructure's suitability for cycling. The main methods collected in the literature are presented in table 1.

Method name	Acronym	Reference	Date
Bicycle Safety Index Rating	BSIR	Davis	1987
Bicycle Stress Level	BSL	Sorton and Walsh	1994
Road Condition Index	RCI	Epperson	1994
Interaction Hazard Score	IHS	Landis	1994
Bicycle Suitability Rating	BSR	Davis	1995
Bicycle Level of Service(Botma)	BLOS	Botma	1995
Bicycle Level of Service (Dixon)	BLOS	Dixon	1996
Bicycle Suitability Score	BSS	Turner et al	1997
Bicycle Compatibility Index	BCI	Harkey et al	1998
Bicycle Suitability Assessment	BSA	Emery and Crump	2003
Bicycle Level of Service (Jensen)	BLOS	Jensen	2007
Bicycle Level of Service (Petitsch et al)	BLOS	Petritsch et al	2007
Bicycle Level of Service (HCM)	BLOS	HCM	2011

Table 1 – Main methods to evaluate infrastructure suitability for cycling (Lowry and Callister, 2012)

The methodology presented by all methods in table 1, follow the same general lines with a score being attributed to each parameter of the infrastructure considered (mainly motorized traffic speed, volume; width of the lane and of the sidewalk) (Lowry and Callister, 2012).

These methods evolved to an approach to Bikeability based on the concept of accessibility. Main methods revolving around this concept are those by Iacono *et al* (2010), based on a phone survey to calculate accessibly in the city of Minnesota, and by McNeil (2010), which categorized the cycling infrastructure based on its accessibility to main destinations, and Walk Score (2014) that base their classification in the quality of a specific place for bike use.

In the 2010s, a trend of bikeability evaluation methods emerged that consider both suitability and accessibility. (Lowry and Callister, 2012) joined the concept of Hansen's accessibility (Hansen, 1959) to the bike level of service (BLOS) in order to create a *Bicycle Level of Service Score* to characterize the Bikeability of the infrastructure, using GIS. This concept was also explored by Mesa and Barajas (2014), Krenn *et al* (2015) and Lowry, Furth and Hadden-Loh (2016) focusing on the mapping of connections associated with low stress to characterize the cycling infrastructure.

2.4. Use of technology in the analysis of cyclist's experience

The analysis of cyclist's experience while riding a bike has been evolving over years, where the initial methods resorted to GPS information. Menghini *et al.* (2009) developed the first study of this sort and they learned that cyclists only tolerated small deviances from the fastest and more direct route. This concept was explored by several authors, Broach *et al.* (2011), Hood *et al.* (2011), Blanc and Figliozzi (2016), Hudson *et al.* (2012), Casello and Usyukov (2014), Cherry *et al.* (2016) and Chen, Shen and Childress (2017), with the analyses of some other factor such as the opinion of cyclists about the road in which they were travelling and some riding behaviors.

In addition to the revealed references of cyclists, (Yang and Mesbah, 2013) and (Zacharias and Zhang, 2016) studied the connection between revealed and declared preferences, identifying some factors that could change the declared preferences from the preferences that they actually present.

In addition to GPS information, other methods incorporated different technologies. Lehtonen *et al.* (2016) combined video data with GPS information and found that the perception risk is higher in more experienced cyclists, than in least experienced drivers. Zeile *et al.* (2015) and Figliozzi (Figliozzi, 2016) added the detection of physical parameters to GPS information, with the last study detecting a clear difference in stress when the cyclist was circulating in the pick hour comparing to a non-pick hour.

Viera *et al.* (2016), developed an application and automated process capable of detecting stress events with resource to a cardiac strap and GPS and accelerometer data from the smartphone application.

3. Methodology

This dissertation follows a four-stage methodology: 1) Classification of cyclist volunteers based on questionnaire and of the infrastructure, according to international guidelines, 2) field experiment with volunteers, data collection and transmission to the server; 3) data analysis, and 4) identification of cyclists' behavioral indicators that allow to defining the bikeability of paths – whether these are road carriage ways or dedicated bike lanes/paths (refer to Figure 1).

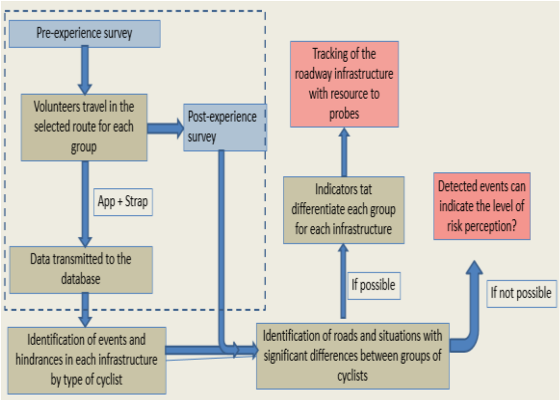


Figure 1 – Methodology adopted

In the first phase, a group of 21 volunteers were selected and included in the various types considered in the present dissertation and the roads and paths they would take were defined.

After, experimental procedure was undertaken and a transmission of data to the database with its subsequent analyses. Finally, we compared and analyzed the behavior of the different types of cyclist when they were sing in the same category of infrastructure. Differences in behavior could indicate if the hierarchy and characteristics of the types of roads in which they rode, would unveil the appropriateness of those routes to those different types of cyclists. Eventually, cyclist behavioral standards would be defined for different types of cyclist when riding different types of cycling network components.

4. Case Study

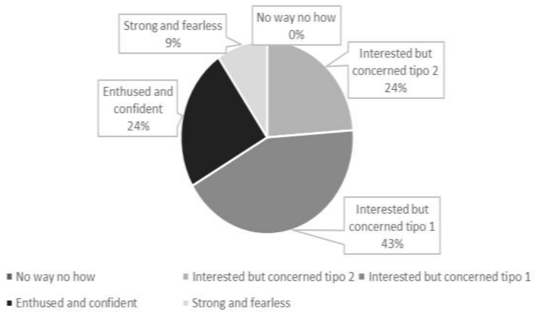
In the present dissertation, we opted for Geller's classification, Geller (2006) with the inclusion of an additional group, resulting from the segregation of the group interested and concerned in two. The characteristics of each group, can be seen in table 2.

Type	Characteristics
SF - strong and fearless	They are regular cyclists and ride bikes regardless of the infrastructure conditions
EC - enthused and confident	They are regular cyclists and capable of circulating in mixed infrastructures, generally undeterred by roadway conditions, but prefer dedicated cycling network
IC1 - interested but concerned type 1	Although knowing and like riding bikes, they are not regular cyclists and uncomfortable in situations of high traffic speed or volume. Could share calm roadways with cars.
IC2 – Interested but concerned type 2	Like previous, but they are only comfortable in segregated bike paths or lanes and are not capable to cycle regularly
NWNH – No way No how	Not interested in using bicycle regardless of the infrastructure

Table 2 – Characteristics of the types of cyclists considered (adapted from Geller, 2009).

Based on these characteristics, volunteers were classified to fit one of the previous groups based on a questionnaire that, besides a brief sociodemographic characterization, asked the volunteers to score attitudinal and perception of risk questions to differentiate their tolerance with respect to different types of roadway conditions.

The classification resulted in 2 elements being SF, 5 EC, 9 IC1, and 5 IC2. No volunteers were



NWNH (refer to Figure 2 for the distribution of volunteers according to our classification).

Figure 2 - Distribution of the volunteers by group

Together with the classification of the volunteers, the infrastructure was hierarchized based on the traffic speed, traffic volume, number of lanes, existence of parking and vehicles stopped in the lane. Refer to Figure 3 for an example of the routes designed for the experiments.

Figure 3 – Example of route definition for the experiments, according to each group of cyclists.

Based on these parameters, Av. Berna was considered as the road which would offer more difficulties to most volunteers, and only comfortable for SF. Av. 5 de Outubro and a segment of Av. Marquês de Tomar (B) was considered as adequate for EC and SF. Av. Marquês de tomar (A), Av. Defensor de Chaves (A) and Av. Elias Garcia were allocated to IC1 and cyclists above, due to the corresponding low traffic volumes and speed. Av. Duque d'Ávila and Av. da República that have segregated bikeways were allocated to IC2, although the former can have many conflicts with pedestrians.

The routes selected for each volunteer were picked in a way that included at least one type of infrastructure in which they felt comfortable, and another in which they felt uncomfortable, so that we could measures differences in riding and behavioral measurements.

After the inclusion of each volunteer in a group and the selection of the route they had taken the cyclists were equipped with a cardiac strap and sensor, *Zephyr Bioharness 3*, to measure biometric parameters that allow the identification of stress peaks, a smartphone to collect GPS data and accelerometers and gyroscopic measures and a GoPro to collect video.

5. Results

After the experience, the experimental routes were divided in shorter uniform segments of up to 200 meters, approximately, besides separation at each intersection (and 15 meters before the intersection).

The route for IC2 was segregated in 29 segments, for IC1 in 49 segments and for EC and SF in 41 segments.

Video post-processing was performed to identify hindrances present in the roadways and lanes used, which could hinder cyclists and therefor have an impact in their behavior. These hindrances were classified as "dynamic" (e.g., moving vehicles or pedestrians), "dynamic but not in movement" (e.g., vehicles stopped in signalization) and "static" (e.g., pedestrians that are not moving, parked vehicles).

With this information, we could map the number of hindrances in each segment and verify that the *a priori* classification of the routes' risk exposure and difficulty for cycling matched the data collected, except in Av. Elias Garcia, where the number of "dynamic but not in movement" hindrances was overall the second highest value and in Av. Duque d'Ávila, where the number of "static" and "dynamic hindrances" was much higher than what one would expect in a bikeway, as seen in Figure 4.

Figure 4 - Mapping of dynamic hindrances [number of hindrances per segment]

In addition to hindrances, events related with the cyclists driving behavior were also collected, including sudden maneuvers (SM), decelerations (D), stops (S), time to overtake other vehicles (O) and times to be overtaken by other vehicles (BO).

Generically (for all segments analyzed – refer to tables 3 to 6)), we verified that there was an increasing trend on the number of overtakings (O), as the cycling proficiency increased from IC2 to SF, ultimately. Conversely, there was a diminishing trend of the number cyclists being overtaken (BO), the number of decelerations (D) and the number of Stops (S) and sudden maneuvers (SM).

	Type/# events by route				
Cyclist types	SM	D	S	O	BO
IC2	2	8,8	2,6	0,8	6,6
IC1	1,5	4,2	2,2	2,5	6,4
EC	1	1,1	0,6	2,6	2,6
SF	1	1,2	0	2,5	1

Table 3 – Results for Av. Marquês de Tomar A

In Av. Elias Garcia, table 4, the same trend occurred, but the comfort felt by users of group IC1 doesn't seem to be as high. This may be due to the higher number of maneuvers made due to the presence of many "dynamic but not in movement" hindrances.

	Type/# events by route				
Cyclist types	SM	D	S	O	BO
IC2	3,8	11,6	3,4	2,2	3,8
IC1	3,7	7,7	3	6,8	1,9
EC	1,6	4,2	2,4	6,6	1,4
SF	2	4	3	9,5	0,5

Table 4 - Results obtained for Av. Elias Garcia

In Av. 5 de Outubro, Table 5, and Av. Berna, Table 6, the data obtained also suggest a reduction in comfort as the group decreases.

	Type/# events by route				
Cyclist types	SM	D	S	O	BO
IC1	4,5	9,1	3,3	2,5	9,6
EC	2,2	3	2,8	3,6	7
SF	2,5	4,5	1	7,5	5

Table 5 - Results obtained for Av. 5 de Outubro

	Type/# events by route				
Cyclist types	*SM*	*D*	*S*	*O*	*BO*
EC	3,2	5,8	1,8	6,8	5
SF	2	4	2	12,5	3

Table 6 - Results obtained for Av. Berna

An analysis of the stress peaks detected by the cardiac strap has also been done in a qualitative way, due to the low number of valid samples (15). In this case a correspondence between peaks and real live situations that may have caused those peaks was made.

6. Conclusions and future studies

The information collected through the experimental procedure with the cardiac straps and sensors seem to indicate that the situations identified by each group as uncomfortable were in fact corresponding to some hindrances that would be prone to the stress peaks detected.

Although the experiment's sample size being small, overall results suggest that the cycling indicators of volunteers for each group match the expected behavior according to the hierarchy level of each route segment designed for the experiment. We recall that this hierarchy levels were defined according to risk exposure and comfort levels for the cyclist.

The obtained results also indicate that there may be a correspondence between the driving behavior of a cyclist from a specific group and the characteristics that the roads in which they travel present, meaning the concept inherent to the first hypothesis considered in the present dissertation was somehow corroborated, allowing for a proof-of-concept, to be further explored. Still, the sample size does not allow for a full statistical validation of the concept. As such, it would be of great interest to increase the sample size collected to further explore the presented concept.

It would also be of great importance the improvement of the material used, with a higher quality video recorder that would allow for the collection of viable data for the automated processing, reducing possible errors of human post-processing of the videos, done in this research.

A cardiac strap with less sensibility and more accuracy could also bring information of great value to this study, with more information regarding the stress inducing situations.

With these enhancements, the concept presented could be tested more thoroughly, which would rely on an identification of a larger number of probe cyclists for each group. These would have to reply the questionnaire and classified accordingly in each of these 5 groups of cycling proficiency. Thereafter, when riding with the required equipment operational, they would be able to characterize the cycling network, automatically, and define appropriate levels of comfort and risk exposure for the different types of cyclists, building eventually a map of risk exposure to cyclist for the urban area analyzed.

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