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Combining environmental quality assessment of bicycle infrastructures with vertical acceleration measurements

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A R T I C L E I N F O

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A B S T R A C T

Growing interest in zero emission transport modes, such as cycling, is currently generating motivation to construct new cycle paths. However, transportation planners and managers cannot always rely on practical methods for allocating the resources (often limited) needed for inventories and assessing cycling infrastructures. The aim of this study is to develop a method for classifying cycle paths in terms of roughness and general conditions of the pavement surface. Inventory data and information regarding the infrastructure conditions were collected on-site using video recordings taken by an action camera directly mounted on a bicycle. Georeferenced vertical acceleration data were collected using a smartphone. Acceleration data of three different pavement surfaces (asphalt, concrete and concrete bricks) were registered. The results showed the lowest acceleration values for concrete pavement and the highest values for interlocking concrete pavement. The proposed method can be a practical and efficient approach to evaluate cycling infrastructures in terms of pavement condition.

1. Introduction

Traffic congestion, noise and air pollution are nowadays common issues in urban areas. As these growing problems are all strongly associated with motorized transport modes, cycling is becoming an attractive alternative for urban transportation. The success of cycling as a viable transport mode depends, however, on the conditions of the infrastructure, given that safety and comfort are essential to attract new users (Dill and Carr, 2003; Pucher and Buehler, 2007). In addition, proper maintenance of cycling infrastructures is equally important for the different parties involved in urban planning and management of public financial resources.

With the expansion of transport infrastructure management systems, database integration has become a sensitive matter for managers and government agencies. GIS (Geographic Information Systems) tools are highly potential in terms of facilitating these integration processes due to the capacity of combining geographical characteristics with tabular data. The inventory phase, for example, which is essential in infrastructure management systems, can clearly benefit from GIS tools. Data collection and analysis at a network level, which is extremely useful for planning, programming, budgeting, operational management, assessing and identifying potential points for improvement, is another interesting application of GIS for transport infrastructure management systems (Haas and Hudson, 2015). Nevertheless, despite the importance of the inventory phase, Nuñez and Rodrigues da Silva (2016) found in the literature that data collection is often exclusively based on questionnaires conducted with users and subjective criteria.

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Even though management systems for cycling infrastructures are not very common yet, Gharaibeh et al. (1998) developed a cycle path management system at the University of Illinois in the USA almost two decades ago. The system inventory includes information about the general characteristics of the infrastructure, as well as assessment reports of the pavement conditions based on field data. Physical characteristics of the paths, such as surface defects, painting and rolling conditions, vertical displacements, geometry, etc., are classified on a severity scale with five levels. The system is well designed, but it relies on visual inspections and users' subjective assessments of the rolling conditions. It does not include objective measurements of vibrations, environmental comfort or any other variable of the physical environment around the infrastructure.

Given the difficulties and even risks of accidents that pavement surfaces in poor conditions can cause to cyclists, this study proposes an alternative method to assess the pavement conditions on cycle paths. Data for the inventory and assessment of the conditions of this important infrastructure element are collected using a smartphone and a video camera. The vertical acceleration data are transferred to a GIS package and subsequently used for a comprehensive analysis, as well as with other variables related to the cyclists' comfort and environmental attributes around the cycle paths (video recorded).

2. Literature review

This section aims to review and summarize the literature related to methods for assessing cycling infrastructures, using smartphones and Global Position Systems to evaluate bicycle infrastructures and assess vibrations on cycleways. The focus is heavily on the pavement quality.

2.1. Methods for assessing cycling infrastructures

Based on a literature review conducted for this study, we found the following methods for cycling infrastructure design and evaluation as the most common to assess the quality of service of cycleways: the level of service approach for bicycles of the Highway Capacity Manual developed for the United States (HCM, 2010); the Danish Bicycle Level of Service - DBLOS (Goodno et al., 2013) and the Bicycle Environmental Quality Index - BEQI, developed in California, USA (SFDPH, 2009, 2014). The particularity of these methods is that they have been calibrated from survey models and include the condition of the pavement surface as a factor based only on subjective evaluations. The BEQI method assesses the characteristics of cycling infrastructure based upon the visual assessment of street segments by a trained observer. This index assesses the bicycle environment on roadways and qualifies the conditions of the cycleways.

We also found technical manuals, such as the UK guidelines for cycling projects (James, 2015), documents from State Departments of Transportation (DOT) in the United States (Olson et al., 2016; Magalotti, 2013), manuals and reports from transport authorities in Australia (AUSTROAD) (van den Dool et al., 2014) and documents drawn up by the American Association of State Highway and Transportation Officials (AASTHO, 2012) and requirements for high quality cycling infrastructure design in Vienna, Austria (Brezina et al., 2012). These manuals provide recommendations about how the cycleways should be designed. However, they do not propose a way to carry out an inventory and evaluation of the different components and pavement conditions of cycleways. In addition, none of them have included vertical acceleration measurements along the route in their pavement condition indicators. These methods lack detailed information of the pavement conditions such as types of surface and distress on pavement surfaces.

2.2. Smartphones and global position systems used to plan and evaluate cycleways

Using Global Positioning Systems (GPS) is currently almost a mandatory condition in data collection procedures for inventories and evaluating transport infrastructures. Some authors have used GPS for demand studies, for example (Harvey et al., 2008; Menghini et al., 2010; Hood et al., 2011; Broach et al., 2012; Casello and Usyukov, 2014; Jackson et al., 2014; Segadilha and Sanches, 2014). GPS receivers were also combined with dedicated accelerometers to evaluate pavement conditions (Benbow et al., 2006; Yamanaka and Namerikawa, 2007; Olieman et al., 2012; Macdermid et al., 2014; Bíl et al., 2015; Takahashi et al., 2015; Ambrož, 2017; Joo et al., 2015; Joo and Oh, 2013; Calvey et al., 2015). A smartphone app GPS was used by Strauss et al. (2017) to investigate the relationship between reported cyclist road injuries and the safety of cycle paths. Nowadays, with the development of electronic devices such as smartphones, using embedded sensors with georeferencing has made it easier to incorporate measures of these devices into the inventory and evaluation methods of cycleways.

Smartphone apps are already an alternative for collecting data from transport system users due to GPS records embedded into these devices. An example of a smartphone application for cycling systems is CycleTracks. Other versions of this app were used in other cities in the USA (SFCTA, 2017). These apps were used in bicycle travel demand studies to identify, for example, user preferences. Other smartphone applications, such as Strava and Endomondo, have been developed to provide information about performance, calories burned, etc., during cycling trips.

However, using smartphone accelerometers and action cameras to collect information about cycling infrastructures is not so common. One exception is a study conducted by Vieira et al. (2016), in which smartphone GPS data were combined with information obtained from an action camera (to evaluate the general path conditions) and a cardio signal acquisition belt to evaluate cyclists' stress levels. In this case, however, the video images provide only general information about the cycleway, without any detailed analysis of the pavement conditions (types of surface, types of distress, severity levels and extension) or a comprehensive assessment of the cycle path surroundings.

2.3. Vertical acceleration and vibration on cycleways

Roughness caused by large cracks, bumps, potholes and loose gravel could cause undesirable vibrations and put cyclists at risk of falling. In addition, cyclists' comfort is directly associated with the vibrations caused by pavement surface irregularities. According to Griffin (1990), human perception depends on vibration magnitude, frequency and duration. Exposure to strong and long-lasting vibrations may cause health problems (Gemne and Taylor, 1983; NIOSH, 1997; Griffin and Bovenzi, 2002). On the other hand, a smooth surface also means less energy is consumed by the cyclists (Vanwalleghem et al., 2012).

The ranges of vibrations and frequencies that affect the comfort and health of human beings have been discussed by various authors, such as Giubilato et al. (2014), Matsumoto and Griffin (1998) and Miwa (1975). Other authors have analyzed the direct effect of wavelengths on the perception of the quality of the trip (Ron, 1994; Cairney and King, 2003; Benbow et al., 2006; Barbudo et al., 2015; Thigpen et al., 2015). According to Benbow et al. (2006), user perception studies show that the profile wavelengths that cause users most discomfort are those in the range of 1–5 m. Wavelengths between 5 and 10 m have some impact on comfort perception, and values larger than 10 m have no effect on user perception.

Accelerometers can be used to determine the characteristics of the vibrations on cycleways (Wigan and Carney, 1985; Torbic et al., 2003; Hastings et al., 2004; Levy and Smith, 2005; Champoux et al., 2007; Yamanaka and Namerikawa, 2007; Du et al., 2009; Giubilato and Petrone, 2012; Hölzel et al., 2012; Olieman et al., 2012; Vanwalleghem et al., 2012; Arpinar-Avsar et al., 2013; Duvall et al., 2013 – case of pathways used by wheelchairs; Macdermid et al., 2014; Parkin and Sainte Cluque, 2014; Ayachi et al., 2015; Bíl et al., 2015; Chou et al., 2015; Li et al., 2015; Takahashi et al., 2015; Ambrož, 2017). These investigations have shown the importance of measuring vibrations to evaluate the quality of the cycleways and the close relationship with user comfort. Considering that accelerometers are now common devices in smartphones, measurements obtained from them could be used in a simple and intense way to evaluate the quality of cycleways.

3. Research objectives

In general, using smartphones to support data collection for cycling studies has so far focused mainly on the physical performance of cyclists, demand and flow data (e.g. speed). As a consequence, the potential of several other sensors also available for smartphones, such as the one used in this study, have not yet been fully investigated to assess the conditions of cycling infrastructures.

The objective of this study is to complement the BEQI method by evaluating the condition of the cycling infrastructure using video recordings, GPS and accelerometers embedded in smartphones. Based on analysing and observing the characteristics of the infrastructure from the video recordings, a database can be created. This database can be later complemented with the georeferenced data of vertical acceleration to obtain a complete evaluation of the conditions of cycleways. This development from BEQI aims to add information to an objective and detailed evaluation of the quality of the surface on which cyclists ride.

4. Method

The method introduced here was developed for improving data collection and other procedures required for assessing important components of cycling infrastructures, with a particular emphasis on the pavement surface. The approach is based on the Bicycle Environment Quality Index (BEQI), which is a consolidated and relatively recent method developed for evaluating the general conditions of cycling infrastructures (SFDPH, 2014). The original method adopts a concept of deductible values (borrowed from roadway pavement management systems) on a 1–100 scale, in which 100 is the best condition. It also takes into account the general conditions of the environment around the cycle paths. Currently, user comfort analysis, indicated by the BEQI method, is based on the visual assessment of street segments by a trained observer. In this study, a method of simultaneous data collection of all information related to the quality of cycle paths is proposed, and comfort is indicated by an objective classification of the data. Our approach adopts the following procedures: i) inventory data collection, ii) vibration measurements, and iii) infrastructure assessment.

4.1. Inventory data collection

The data collection procedures were all conducted directly using a bicycle (Table 1 and Fig. 1). A video camera was adapted to the bicycle frame to help identify the different elements distributed along the cycle paths. A smartphone was fixed to the bicycle frame, under the saddle, to register vertical acceleration values and the associated vibrations along the way. All the information was georeferenced by the GPS data obtained from the smartphone. In order to synchronize the GPS and the accelerometer during the data

Table 1
Main characteristics of the bicycle used for data collection.

Material frame	Aluminum
Size frame	Small
Wheel size	27.5 in.
Tire pressure	40 psi
Suspension fork	Blocked for tests
Total bicycle mass	12.5 kg

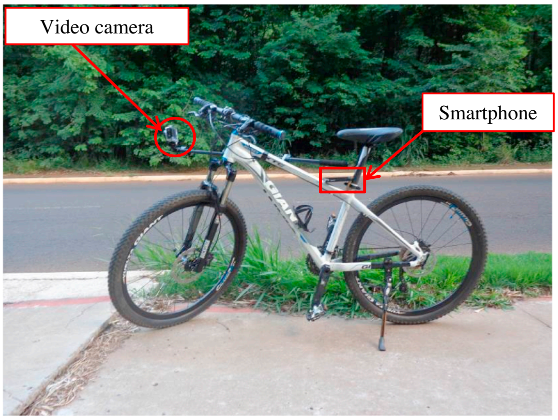

Fig. 1. Bicycle with equipment used for inventory data collection.

acquisition, a program was specifically developed in R software. The input data used by the program are found in .csv and .gpx format files. The program automatically extracts the characteristics, classifies them and builds databases that can be directly exported to GIS software or directly visualized using mapping routines of R.

4.2. Vibration measurements

Analysis of the vibration levels on the cyclist's body were based on recommendations from ISO 2631-1, which was issued by the International Organization for Standardization (ISO, 1997). In our evaluation, however, we considered only the vertical acceleration (the z direction informed by the smartphone), because that is essentially how the irregularities on the pavement surface are perceived by the cyclists. Acceleration values were classified according to the Root Mean Square of Vertical Accelerations (Eq. (1) and Table 2). The first column of Table 2 indicates that ISO 2631-1 explicitly recognizes an overlapping of classes. In our case, the overlapping was not considered (as shown in the second column of Table 2), merely to prevent that any values may simultaneously belong to two different classes.

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} {x_i}^2} \tag{1}$$

where N corresponds to the N^{th} value in a 5 m interval and x_i are the vertical acceleration values collected along the way.

As the adopted data collection strategy generates a large volume of data, we decided to spatially aggregate the acceleration data. Groups of RMS values obtained for every 5 m interval could then be classified according to the limits suggested in ISO 2631-1 and the outcomes subsequently mapped to show the locations with the largest vibrations. The sampling rate of the acceleration was 50 Hz. A time-frequency analysis was carried out to assess the typical frequencies of the different types of pavements inspected.

4.3. Infrastructure assessment

For the assessment of the cycling infrastructures, the videos must be analyzed together with the information registered in inspection forms filled in for the different segments of the cycle paths. The inspection form was based on a data sheet developed for rating the conditions of asphalt and concrete pavements of cycle paths (Gharaibeh et al., 1998). We added fields for registering information about the following aspects: signaling, drainage, environment, obstacles, geometry and accessibility (Turner et al., 1997) (Table 3). For interlocking concrete pavement, the inspection form was based on the distress manual issued by the Interlocking Concrete Pavement Institute (ICPI, 2007). Regarding the weights associated with the indicators, we adopted the same values

Table 2
Comfort perceptions for different vibration levels (adapted from ISO 2631–1).

Acceptable values of vibration magnitudes for comfort (m/s^2)		Likely users' reactions
As in ISO 2631-1	Values used in this study	
Less than 0.315	Less than 0.315	Not uncomfortable
0.315–0.63	0.315–0.63	A little uncomfortable
0.5–1	0.63–1	Fairly uncomfortable
0.8–1.6	1–1.6	Uncomfortable
1.25–2.5	1.6–2.5	Very uncomfortable
More than 2.5	More than 2.5	Extremely uncomfortable

Table 3
Indicators and weights used for infrastructure assessment based on the BEQI method (adapted from SFDPH (2009)).

Traffic 30.8%	Safety/other 9.3%	Land use 14.6%	Street design 45.4%
Motor Vehicle Traffic (Volume and speed)	Control signs and markings	Sight distance	Curve frequency
	Drainage (part of the road/cycle path)	Bicycle parking	Accessibility/connectivity
	Ponding	Land use	Trees
	Obstructions		Pavement defects
	Presence of pedestrians		Asphalt* Concrete** Interlocking***
	Trees, poles, bollards		
	Manhole		
	Debris		
	Faulting		
	Potholes		
	Edge drop-offs		
	Bumps		
	Lighting		

Asphalt pavement defects*	Concrete pavement defects**	Interlocking concrete pavement***
Cracking	Raveling	Damaged pavers
Patching	Spalling/scalling	Depressions
Raveling	Faulting	Edge restraint
Train crossing/rough crossing	Settlement	Excessive joint width
Pumping	Cracking	Faulting
Rutting		Heave
Pumping		Horizontal creep
Shoving and corrugation		Joint sand
Bleeding		Loss/pumping
		Missing pavers
		Patching
		Rutting

originally proposed for BEQI (SFDPH, 2009), shown as percentages in Table 3. In this study, we consider the domain of segments, i.e. excluding intersection domain analysis.

Once the campaigns were made, the videos were analyzed, taking 100-meter segments as a reference. From field observations, data from each segment is added to a spreadsheet. By using this spreadsheet, both aspects considered in the BEQI, as well as those that were added in Table 3, can be systematically counted. The spreadsheet generated with the values of the BEQI was imported into R software to be analyzed with acceleration values and visualized in the form of maps. The developed program can process the data quickly. As of the moment in which the data of the campaigns were obtained, the process of filling in the spreadsheet and obtaining the maps did not take more than 30 min for an extension of approximately 2 km.

A global assessment strategy was subsequently adopted, in which the final values obtained from BEQI were combined with the vibration measurements, in both cases as rankings. In the first list, higher BEQI values are associated with better conditions of the infrastructure. Vibration measurements, on the other hand, have an opposite interpretation (i.e. higher values are more uncomfortable for the cyclists).

5. Results and discussion

The proposed method was applied in São Carlos, which is a medium-sized city in the state of São Paulo, Brazil. Most of the outcomes of the procedures described in Section 3 were stored in a GIS environment, which helps analyze the results and, as a consequence, manage the cycling infrastructures. The main results of the application are presented and discussed in this section.

5.1. Inventory

Developing cycling infrastructures is a relatively recent process in Brazil. Following the general trend of the country, cycle paths were implemented in the city of São Carlos only in 2009. Moreover, the process was not fast, as summarized in Table 4 and shown in Fig. 2. Despite the limited extension of the existing network, not all stretches were selected for the trial application discussed in this paper. The five cycle paths selected (Fig. 3), however, have distinct characteristics. These characteristics, which include attributes of the surrounding environment, were registered in the inventory process and subsequently stored in a GIS database.

5.2. Vibration measurements

A 33 year-old male cyclist was responsible for collecting all the data, which reduced the variability in the process. In addition to constant body characteristics (64.5 kg and 1.71 m, for example), he tried to keep a regular speed between 15 and 20 km/h. The results

Table 4
Main characteristics of cycle paths constructed in the city of São Carlos, Brazil.

Name	Length (m)	Year opened
Torres	1320	2009
Av. Trabalhador*	205	2010
SESC	734	2011
Trabalhadores 1	1255	2011
Trabalhadores 2	1012	2011
Comércio Chaminé*	1360	2012
SESC*	1690	2013
Artes*	990	2014
Ciclovia Parque Faber*	1690	2014
Trabalhadores 3	1872	2016
TOTAL	**12,128**	

* Selected for analysis in this study.

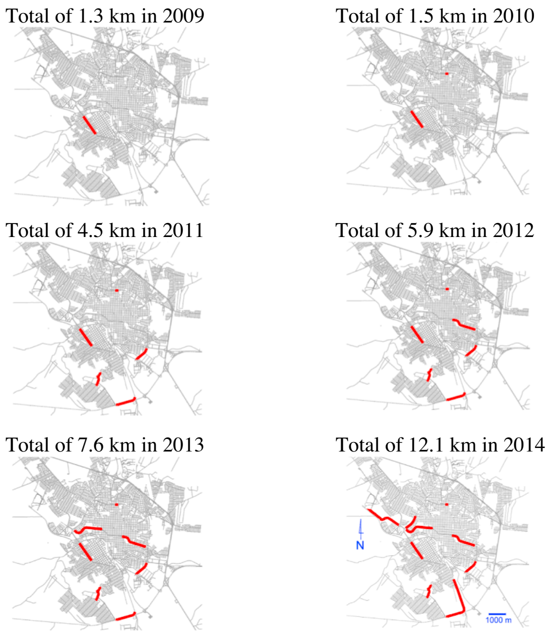

Fig. 2. Development of the cycling infrastructures in the city of São Carlos, Brazil.

of the vibration measurements were used to produce maps of RMS values grouped every 5 m (as in Fig. 4). The classification levels defined in Table 2 are shown in different colors to indicate the comfort perceptions for different vibration readings. Red was used to represent the worst conditions. These are high priority points for maintenance interventions planned to improve the comfort conditions for cyclists.

Typical patterns associated with the pavement material and maintenance conditions of the paths were detected considering the spectral analysis of the different cycle paths. Two amplitude regions were observed regarding the vertical acceleration signals based on the frequency peaks (Fig. 5): values below 20 Hz and values above 20 Hz. High frequencies were predominantly observed on the cycle paths with irregular surfaces, such as "*Faber Cycleway*" and "*Av. Trabalhador Cycleway*".

5.3. *Infrastructure assessment*

Table 5 shows descriptive statistics with measures of central tendency and dispersion for the vertical acceleration measurements and BEQI results.

The results of the evaluation based on BEQI values are shown in Fig. 6. The red points indicate a low index value, which means that these are the locations that are on the high priority list for improvement. The same logic applies to Fig. 7, in which RMS values are also color-coded. Red points are those highly uncomfortable to the users. Therefore, these are priority locations for maintenance interventions from this point of view. Independent rankings of the results obtained from the two approaches were subsequently combined in a single list. This final list was a combination of the values of the independent rankings, which produced a new ranking, as shown in list 4 of Fig. 8. Once again, red was used to show the worst conditions. Locations with high priority levels in both lists

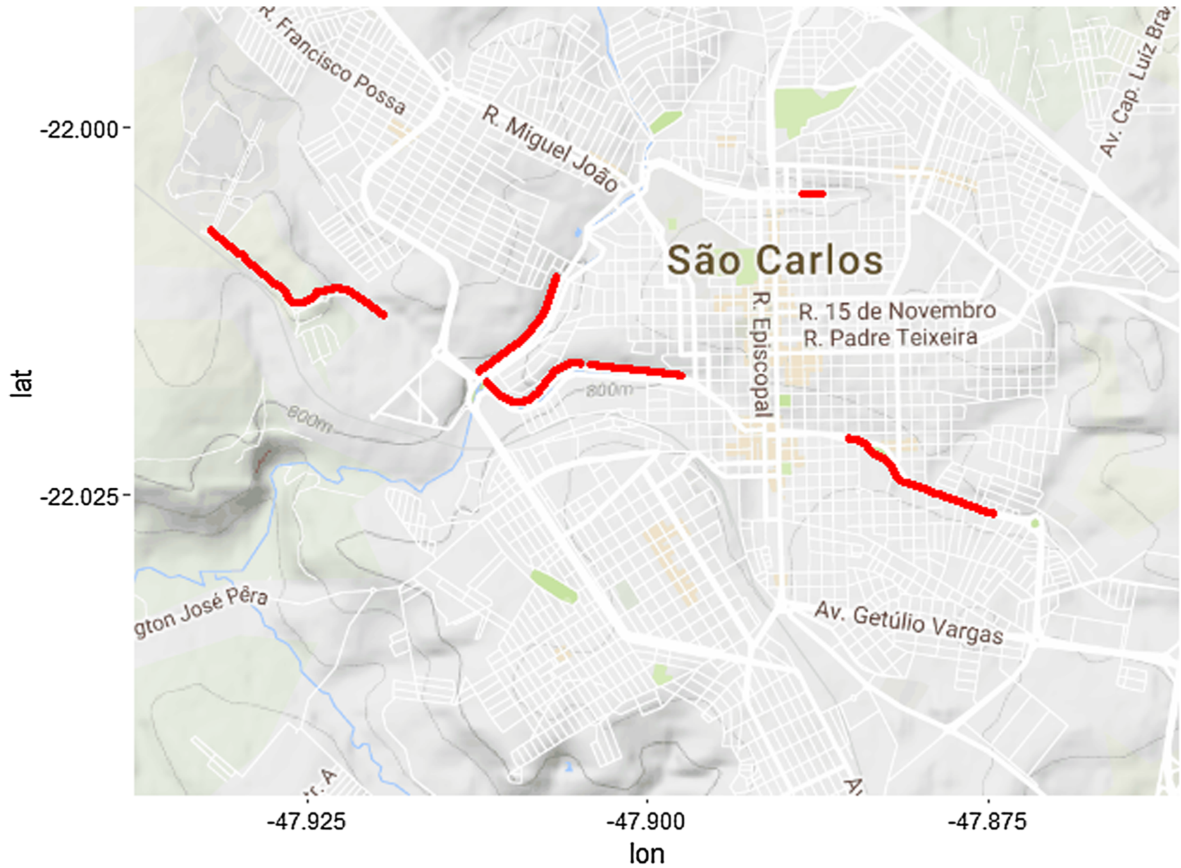

Fig. 3. Cycling infrastructures selected for this study in the city of São Carlos, Brazil.

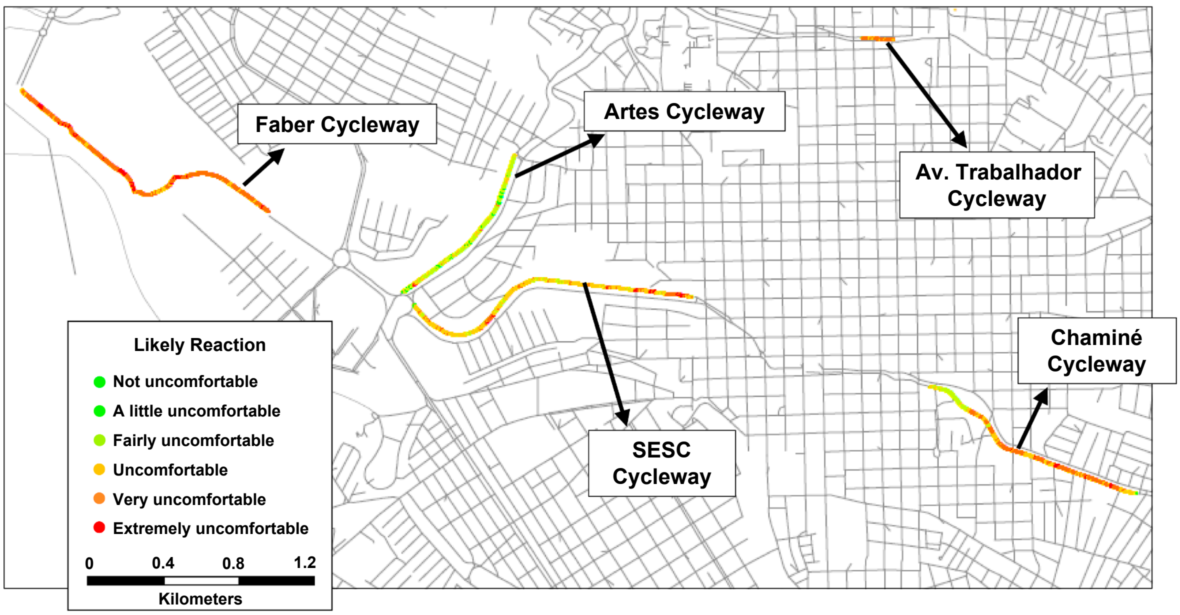

Fig. 4. Vibration comfort of cycle paths based on ISO 2631-1.

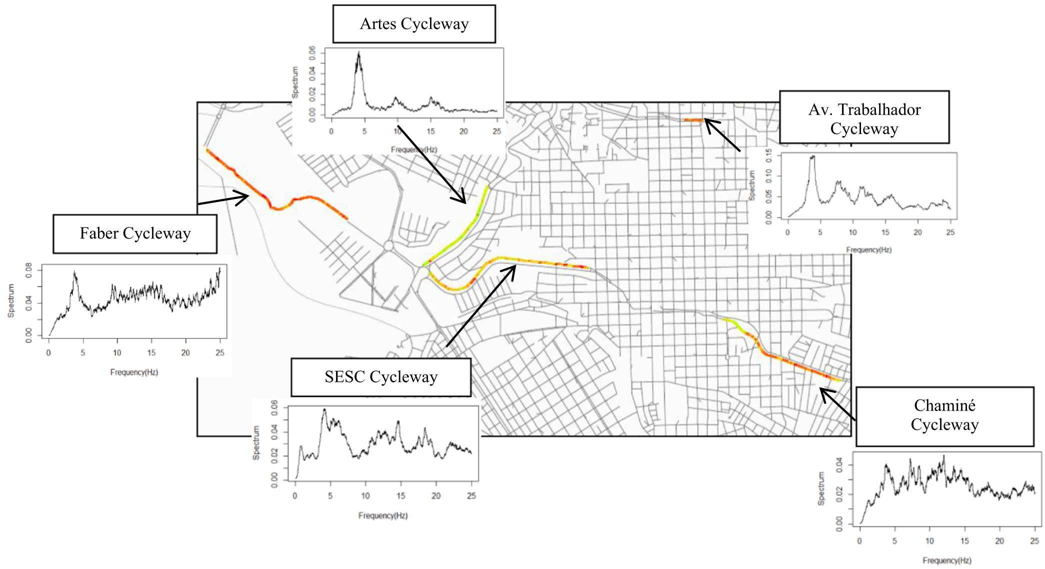

Fig. 5. Frequency spectrum of the acceleration amplitude.

Table 5
Descriptive statistics for vertical acceleration and BEQI results.

Cycleway	Min.	1st Qu	Median	Mean	3rd Qu	Max.	SD*
Vertical acceleration (m/s^2)							
Artes	0.28	0.70	0.80	0.87	0.94	3.49	0.322
Faber	1.15	1.74	1.95	2.01	2.23	4.54	0.398
SESC	0.35	1.11	1.33	1.51	1.62	8.07	0.731
Chaminé	0.66	1.13	1.57	1.53	1.84	3.66	0.496
AvTrabalhador	0.05	1.63	2.14	2.03	2.43	4.11	0.694
Bicycle Environmental Index (BEQI)							
Artes	71.98	78.86	78.86	78.77	80.58	81.58	2.612
Faber	75.67	78.48	82.11	80.28	82.66	82.66	2.584
SESC	69.59	76.48	78.66	78.99	81.38	85.19	4.086
Chaminé	60.21	62.15	64.29	64.33	66.17	71.07	3.722
Av.Trabalhador	74.58	76.39	81.83	79.48	82.02	82.38	3.113

* Standard deviation.

were identified and mapped, as shown in Fig. 9.

6. Conclusions

This study proposed a low cost and practical method for inventory and assessment of cycling infrastructures based on smartphone sensors and a video camera. The approach was developed to be used immediately in real-world applications aiming to identify priority locations for maintenance and improvement in cycling networks. The following conclusions were drawn from a trial application of the method in a medium-sized Brazilian city:

- The proposed procedures can be effectively combined as an inventory in a single GIS database, in which physical characteristics, construction and maintenance activity periods, and general information are all stored together.
- As anticipated, vibration measurements indicate that comfort values may be strongly influenced by the type of pavement. Concrete pavements, which have a high proportion of frequencies below 20 Hz, consisted of the most comfortable surface. The interlocking concrete pavement, on the other hand, showed a wide spectrum of frequencies above 20 Hz. As a result, it was not comfortable for cyclists, even considering that the case studied involved a recently built infrastructure.
- The combined approach for cycling infrastructure assessment complements evaluations based only on BEQI. Introducing a physical measure to the assessment strategy can easily help identify priority points for intervention, with a broader perspective.

The proposed method is useful to evaluate and compare the conditions of different types of cycling infrastructures using the same data collection procedure. From a practical standpoint, this is a positive point. However, as the results are strongly dependent on

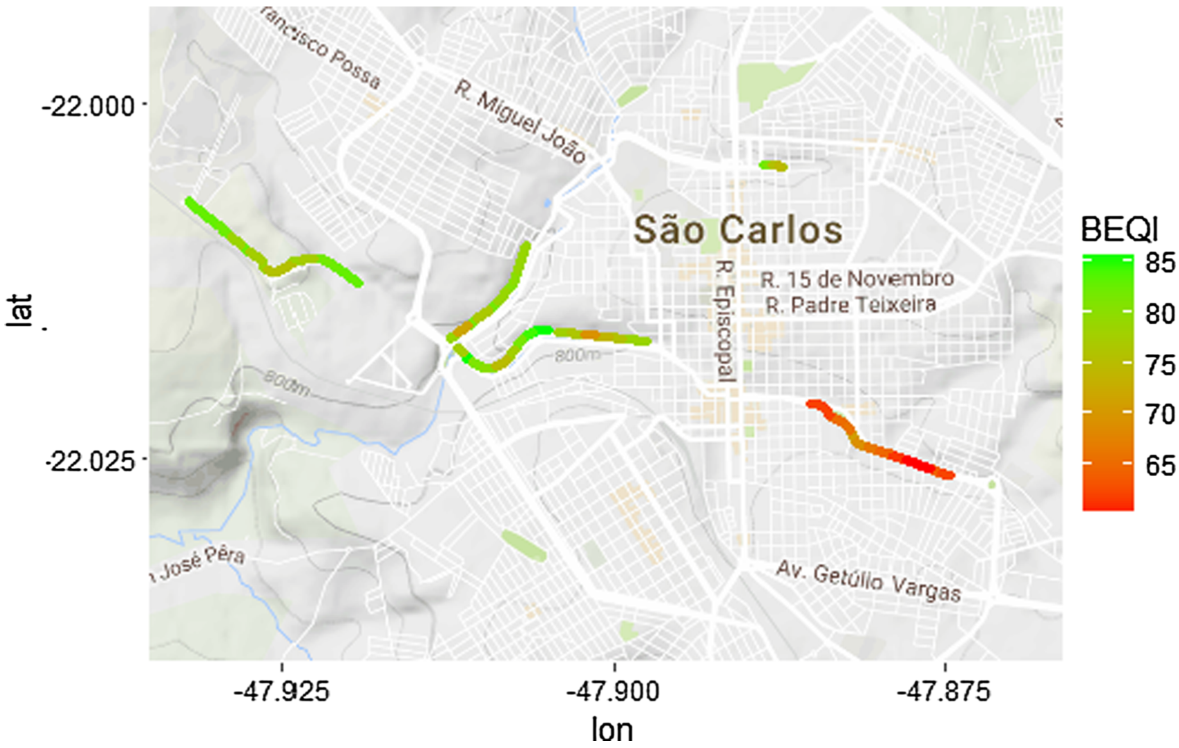

Fig. 6. Infrastructure assessment based only on BEQI values.

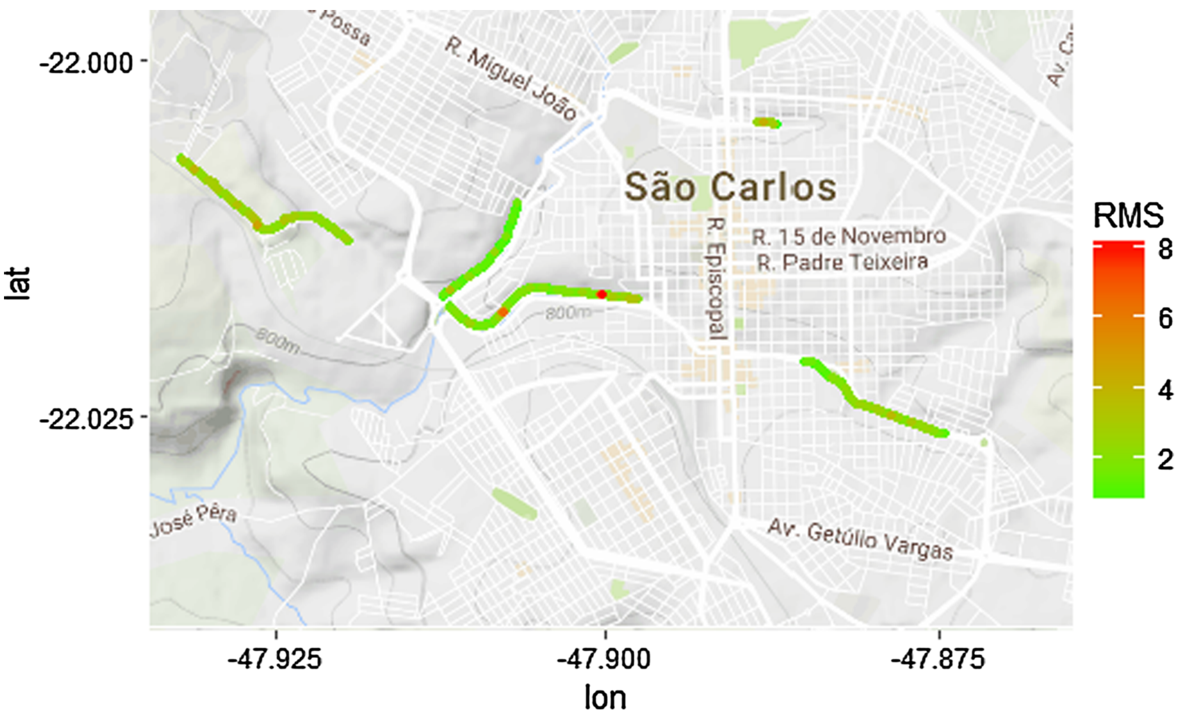

Fig. 7. Infrastructure assessment based only on RMS values.

bicycle features, data acquisition rates and attenuations of the accelerations produced by the smartphone, further research is needed to calibrate the measurement system. The bias resulting from the bicycle used, for example, could be eventually compensated by a dimensionless parameter that is independent of the type of vehicle and cyclist characteristics.

$$\begin{array}{ccccc} & (1) & (2) & & (3) & & (4) \\ \begin{bmatrix} Point \\ ID \\ P1 \\ P2 \\ P3 \\ P4 \end{bmatrix} & \begin{bmatrix} BEQI \\ Rank \\ 3 \\ 2 \\ 4 \\ 1 \end{bmatrix} & \begin{bmatrix} RMS \\ Rank \\ 4 \\ 1 \\ 2 \\ 3 \end{bmatrix} & \rightarrow & \begin{bmatrix} BEQI\,Rank + \\ RMS\,Rank^{(1)+(2)} \\ 7 \\ 3 \\ 6 \\ 4 \end{bmatrix} & \rightarrow & \begin{bmatrix} Combined \\ Rank^{(3)} \\ 4 \\ 1 \\ 3 \\ 2 \end{bmatrix} \end{array}$$

Fig. 8. Example of the procedure used for the combination of BEQI and RMS rankings.

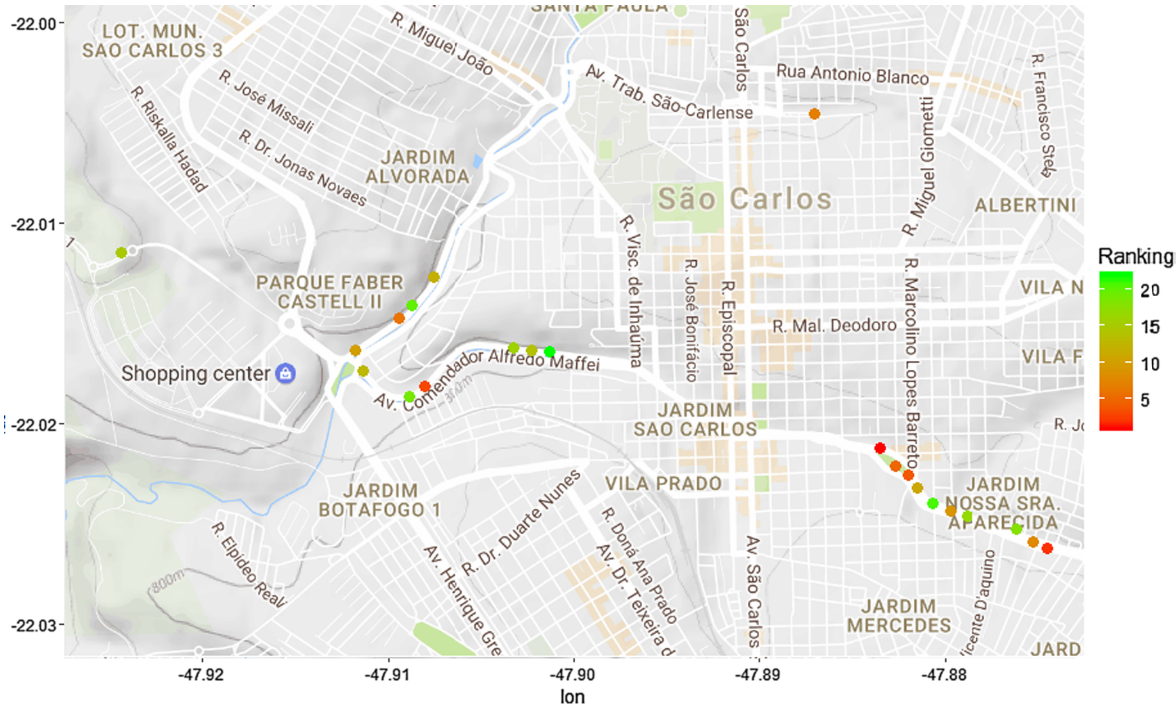

Fig. 9. Selection of the 20 infrastructure locations with the highest priority for improvement based on a combination of BEQI and RMS rankings.

Also, different people (women, people with differing weights/heights, etc.) might not be equally affected. We do believe that this problem was reduced in the present study because our analysis were based on rankings. However, future research could be addressed to adopt this method for a larger sample of people including different genders, ages, type of bicycle, user's characteristics and places. Moreover, other aspects of the data collection procedure could be added or improved, for example video processing techniques combined with machine learning techniques could be implemented to automatically identify the different aspects considered when evaluating the cycle path.

It is also important to keep in mind that ISO 2163 was developed for automobile conditions, in which users normally travel comfortably seated. Therefore, further research must be done to take into account the general path conditions experienced by cyclists. In addition to the particular characteristics (of the vehicle and the infrastructure) that result in vibration, the cyclists' comfort is also closely related to external elements of the environment, such as lighting and greenery. These elements are seldom explicitly considered in management systems for car infrastructures, essentially because in this case users are in a protected environment (i.e. the vehicle itself).

It would be important to study the correlation between the users' subjective evaluation with the objective evaluation proposed. Obviously, the absolute values of acceleration will vary according to the characteristics of the user and the bicycle. However, it is considered that the consistency and assertiveness of the method in relation to the indicative of priority conservation stretches, within a single bicycle lane, and between different bicycle lanes, should be maintained. It is important for this variability to be investigated in future studies, including for calibrating user sensitivity levels proposed by ISO 2163 for the case of cycle paths.

Now that the procedure has already been implemented, it takes about 30 min to plot an outcome map such as the one presented in this study. Fast assessments are crucial for decisions at the operational level. In addition, they can be very useful for actions at the tactical and strategic levels, which may also have an important impact on policy making.

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