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ANALYSIS OF ROAD PAVEMENT BEARING COMFORT THROUGH DATA COLLECTED BY SMARTPHONE AND SERVICIBILITY VALUES

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RESUMEN

Los métodos de evaluación del estado del servicio en las carreteras brasileñas, representados, entre otros, por el *Present Serviceability Index* (PSI), tienen un alto grado de subjetividad en comparación con los métodos más modernos en desarrollo. Estos métodos, entre los que destacan las aplicaciones para smartphones, permiten obtener datos, comúnmente expresados por el *International Roughness Index* (IRI), de forma más rápida. En este sentido, este artículo tiene como objetivo realizar una comparativa entre el PSI y el IRI obtenido por una aplicación de smartphone, en el mismo tramo de carretera. Los resultados muestran, cuantitativa y cualitativamente, que existe una correlación satisfactoria entre los parámetros estudiados.

Palabras clave PSI, IRI, Smartphone

ABSTRACT

The methods of surveying the condition of service on Brazilian highways, represented, among others, by the Present Serviceability Index (PSI), has a high degree of subjectivity when compared to the more modern methods in development. These methods, among which smartphone applications stand out, enable data acquisition, commonly expressed by the International Roughness Index (IRI), to be faster. In this sense, this paper aims to make a comparison between the PSI and IRI obtained by a smartphone application, in the same segment of road. The results show, quantitatively and qualitatively, that there is a satisfactory correlation between the studied parameters.

Keywords *PSI, IRI, Smartphone*

1. INTRODUCTION

According to Hudson et al. (1979), the Pavement Management System (PMS) aims to provide viable strategies to decision makers so that they can intervene in a timely manner and guarantee the useful life of pavements. This is because the infrastructure, due to climatic, traffic or constituent materials, can present defects that, in turn, affect the usefulness and the functional and structural capacity of the pavement. One of the parameters that provide valuable benefits is the International Roughness Index (IRI), especially when dealing with the functional condition of the pavement.

By means of this index, one can infer about the longitudinal irregularity, which besides affecting the safety and comfort of the users, also compromises the useful life of the pavement. Acquiring data on pavement conditions is an important and necessary activity for PMS. In this sense, it can be stated that obtaining the longitudinal irregularity of a pavement in service, depending on the equipment used, requires a high financial cost and demands a long time of survey in situ, when compared to the most modern methods in development in the field of Transport Engineering.

Thus, due to the advancement of technology, new devices are being studied to obtain data on longitudinal irregularity. Various types and methods of surveys (subjective and objective) are known, as well as the differences between them, mainly in relation to the accuracy and the convenience of the data collection.

Medina and Motta (2015) emphasize that the evaluation of the functional condition of the pavement surface allows to estimate the comfort and safety that are being offered to the users. This estimation can be done subjectively, using trained professionals, who assign notes, associating this note with the comfort to the rolling of the vehicles in the stretches traveled. This method, in Brazil, is defined as Present Serviceability Index (PSI). According to the authors, the objective evaluation is desirable, especially with the use of equipment that allows quick data acquisition for the management of the available maintenance resources. In this context, laser profilers and some new equipment developed that also allow this evaluation, such as smartphones and their applications, are inserted.

Considering the above, the objective of this work is to analyze, in a quantitative and qualitative way, the comfort of rolling road asphalt pavement, when comparing IRI values obtained by a smartphone application and by an inertial laser profilometer, with the scores assigned by the PSI.

2. LITERATURE REVIEW

According to DNIT (2006), the defects to which a pavement is subjected tend to promote the increase of longitudinal irregularity, since the sum of the deformations that occur throughout the pavement structure is manifested by the distortions of the longitudinal and tranversal profile. Figure 1 illustrates the contribution of each defect in increasing longitudinal unevenness.

According to DNIT (2006), IRI is the index most frequently used by road agencies in evaluating the use of pavements to the detriment of others, such as the Present Serviceability Index (PSI) and the Surface State Index (SSI). The PSI will be one of the objects of study of this paper. According to Bernucci et al. (2007), the serviceability and the roughness correlate, since the lower the use of pavement, the greater the roughness presented in the surface.

In order to classify the comfort condition to the bearing of a pavement it is important to mention the values and the classification of its surface based on IRI values. In Brazil, there is still no consensus regarding IRI values, even with the National Department of Transport Infrastructure (DNIT). Table 1 shows the differences in the classifications adopted by DNIT (2006) and DNIT (2011), when it concerns, respectively, restoration and management of the pavements of federal highways.

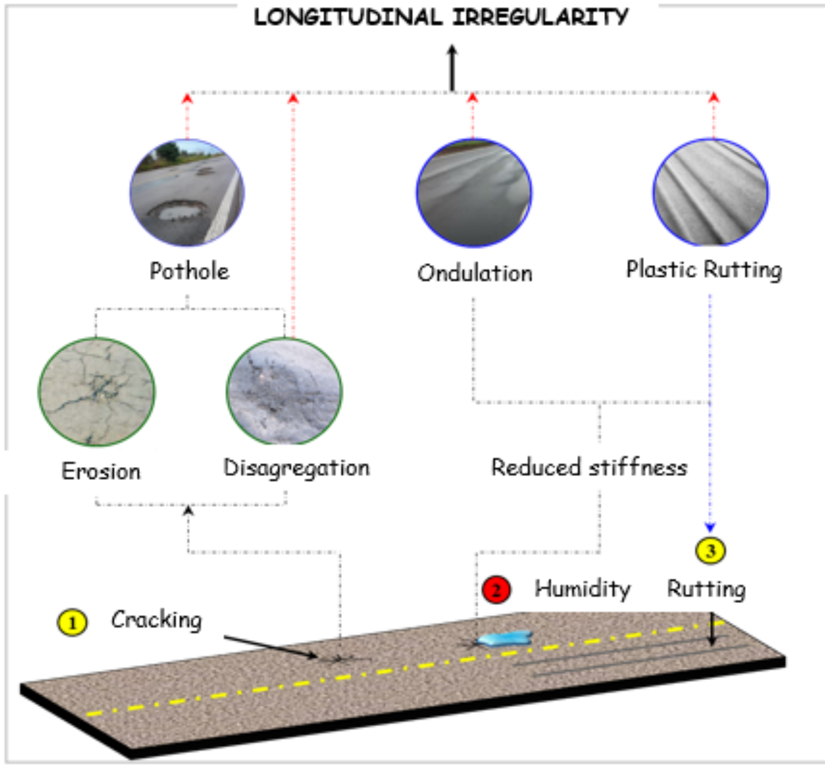

Figure 1 Influence of the defects contributing to the longitudinal irregularity

Table 1 Variations of IRI standards for DNIT (2006) and DNIT (2011)

Traffic Conditions	(DNIT, 2006) (m/km)	(DNIT, 2011) (m/km)
Excellent	1 < IRI ≤ 1,9	IRI ≤ 2,7
Good	1,9 < IRI ≤ 2,7	
Regular	2,7 < IRI ≤ 3,5	2,7 < IRI ≤ 3,5
Bad	3,5 < IRI ≤ 4,6	3,5 < IRI ≤ 5,5
Poor	4,6 < IRI	5,5 < IRI

Medina and Motta (2015) state that IRI values can vary from 0 to 10 m/km for asphalt concrete or surface treatment, and from 0 to 24 m/km for unpaved roads. These ranges are divided into comfort levels associated with maximum operating speeds to maintain smoothness to the bearing. These same authors also affirm that asphalt concrete roads that present IRI between 1.4 and 2.3 m/km and those of surface treatment of 2 to 3 m/km, typically indicate a high-quality pavement.

Regarding methods or equipment for measuring the irregularity, according to Bernucci et al. (2007), there are topographical surveys or by measuring equipment of the longitudinal profile with or without contact, or indirectly by response type equipment, which provide a summation of the deviations of the axis of a vehicle from the suspension. This terminology is due to the fact that these devices measure more the effect of the irregularity in the vehicles and passengers than the irregularity itself. Still for Bernucci et al. (2007), several classifications of irregularity measuring equipment have been employed, depending on the type and principle used for the survey. Sayers et al. (1986) address in a more specific way the classification of irregularity meters, which can be grouped into four classes, the laser inertial profilometer being classified as an Indirect Profile

Measurement System (Class II) and the PSI as Subjective Evaluation Measurement System (Class IV). For smartphones, the authors of this article consider as a Response Type Irregularity Measurement System (Class III).

According to Hirpahuanca (2016) and Douangphachanh (2014), there are situations where irregularity data do not require great precision or it is simply not possible to obtain accurate data. In these cases, a subjective evaluation can be used through previous experience of the evaluator and a visual inspection. In addition to visual inspection, a classification system based on code can be adopted, in which notes are assigned to classify the condition of the pavement surface, typical of the PSI.

With the advent of technology, applications for smartphones were developed for the determination of longitudinal irregularity, mainly due to its low cost, easy operation and high productivity. For Bisconsini (2016), the use of smartphones to evaluate the longitudinal irregularity can be seen as a response type measurement system, although it does not function as a conventional meter, which accumulates the displacements between the body and the rear axle of the vehicle, but it measures the vertical accelerations by means of an accelerometer present in the smartphone fixed internally in the windscreen of the vehicle.

Forslof (2013), Bisconsini (2016), Almeida (2018) and Almeida et al. (2018) commented that there is disbelief around a response type meter, as in the case of smartphones, especially when compared with Class I or II. However, the same authors point out that smartphones can provide updates on the pavement functional condition, in a short time and low cost, compared to other methods.

3. METHODS OF LENGTH OF SERVICEABILITY AND LONGITUDINAL IRREGULARITY FOR THE TRACK ANALYZED

The section in analysis corresponds to a segment of the Highway CE-501, in the city of Fortaleza, state of Ceará, Northeast of Brazil. The segment has a 4.2 km of extension in Asphalt Concrete (AC), executed between 1997 and 1998, with moderate urban traffic composed mainly of buses and private cars. The highway has undergone numerous corrective maintenance interventions throughout its operation, especially with cover-hole services. The composition of traffic for the year 2019 can be seen in Table 2 according to Lira (2019).

Table 2 VMDa Highway CE-401

Sentido	1		2	
Moto	2.408	11%	2.546	12%
Car	12.493	54%	10.436	48%
Bus	670	3%	630	3%
Light Truck	441	2%	468	2%
Medium Truck	1.043	5%	999	5%
Heavy Truck	2.073	9%	1.876	9%
Ultra Heavy Truck	3.650	16%	4.462	21%
Total (2012)	22.777	100%	21.417	100%
Project (2019)	26.163		24.601	

The PSI data were obtained from surveys done by teams formed by researchers from the Department of Transport Engineering of the Federal University of Ceará. The survey was carried out by three teams, which used the same car, during the same morning day in May 2017. The entire survey followed the recommendations of the DNIT procedure (2003). The survey done with the SmartIRI application was carried out in December 2017, also with an average speed of 60 km/h. SmartIRI, according to Almeida (2018), calculates the irregularity of the pavement by providing the IRI value, as well as locating on a map the segments of the stretches that have been lifted. The smartphone is positioned on a bracket and attached to the windshield in the upright position of the same car used in the PSI survey. The APP detects the vertical accelerations imposed on the vehicle due to the presence of longitudinal irregularity, turning this input data into IRI values reported every 100 m. Another survey done with SmartIRI was carried out in the same way in April 2019. It encompassed the passage of the vehicle in all 6 tracks belonging to the highway analyzed, in order to verify the variation of the IRI by track. Likewise, the PSI data for the year of 2017 with the IRI data for the year of 2019 was analyzed. Figure 2 shows the stretches of the analyzed highway in which for the year 2017 a survey for PSI and IRI in the P3 track was carried out, for the year 2019 IRI surveys were carried out for all the stretches.

Figure 2 Section of Highway CE-501

4. ANALYSIS OF IRI RESULTS AND CORRELATION WITH PSI

4.1 Correlation between subjective assessment (PSI) and SmartIRI (Year 2017 – Track P3)

The classification proposed by SmartIRI resembles that proposed by HDM-4 (PIARC, 2010). However, a new class was created, named Excellent. This transposition of the classes was necessary due to the fact that the SmartIRI works as a response type equipment and, in observing the classification proposed by Karamihas and Sayers (1998), it was noticed that old pavements, with IRI of up to 6 m/km, are classified as under normal traffic conditions.

Another reason to carry out the class transposition is that most road coatings in the state of Ceará, where the SmartIRI was developed and calibrated, are executed in Surface Treatments. Due to the executive process, highways with Surface Treatment tend to have IRI values greater than an

Asphalt Concrete coating. Table 3 shows the comparison between the classifications proposed by DNIT (2006), SmartIRI and HDM-4.

Table 3 DNIT classification (2006) and SmartIRI and HDM-4

Traffic Conditions	DNIT (2006) (m/km)	SmartIRI (m/km)	HDM-4 (PIARC, 2010) (m/km)
Excellent	1 < IRI ≤ 1,9	0 < IRI < 2	-
Good	1,9 < IRI ≤ 2,7	2 ≤ IRI < 4	0 < IRI < 2
Regular	2,7 < IRI ≤ 3,5	4 ≤ IRI < 6	2 ≤ IRI < 4
Bad	3,5 < IRI ≤ 4,6	6 ≤ IRI (m/km)	4 ≤ IRI < 6
Poor	4,6 < IRI	-	6 ≤ IRI (m/km)

The application used in the survey, SmartIRI, issues a report in a file generated in .kml format (Figure 3) that allows the user to view the monitored segment by mapping the section every 100 m in a color scale associated with IRI parameters, according to Table 4.

Table 4 Classification proposed by SmartIRI

Classification	Colors
0 < IRI (m/km) < 2 (Excellent)	
2 ≤ IRI (m/km) < 4 (Good)	
4 ≤ IRI (m/km) < 6 (Regular)	
6 ≤ IRI (m/km) (Bad)	

It was observed in Figure 3 that, at the end of the analyzed section, high IRI values were detected, indicating poor traffic conditions, with cracks and patches, as shown in Figure 4.

Figure 3 Map generated by SmartIRI on Highway CE-501

Figure 4 Detail of the end of the section of Highway CE-501

Table 5 shows the classification of the service through PSI and SmartIRI. It is worth mentioning that the values of IRI and PSI have an inverse relationship, since in the former the smaller the value, the better the bearing, and in the later, the opposite happens.

Table 5 Value intervals and qualitative concepts between PSI and IRI

PSI	IRI (m/km)	Classification
0 ≤ PSI < 1	6 ≤ IRI	Bad/Poor
1 ≤ PSI < 2		
2 ≤ PSI < 3	4 ≤ IRI < 6	Regular
3 ≤ PSI < 4	2 ≤ IRI < 4	Good
4 ≤ PSI ≤ 5	0 < IRI < 2	Excellent

The PSI data collected were set out in Table 6. The information was divided into 600 m intervals, totaling 7 segments. With the data in Table 6, the correlation coefficient and determination between PSI and SmartIRI were obtained, as shown in Table 7. The segment was divided into 600 m for the convenience of the authors of this manuscript. Brazilian specifications for functional assessment on flexible pavements recommend segments from 100 to 200 m. For structural assessment, there are procedures that can detect homogeneous stretches, however, for the analyzed stretch, there are no structural data that can support this decision making.

Table 6 Values of PSI and SmartIRI in the sections of Highway CE-501

	Sections	1	2	3	4	5	6	7
	Intervals (m)	0 to 600	600 to 1200	1200 to 1800	1800 to 2400	2400 to 3000	3000 to 3600	3600 to 4100
Team 1	PSI	3,5	4,0	3,8	4,0	3,8	2,3	2,0
Team 2		3,4	3,9	3,8	3,7	3,6	2,7	2,5
Team 3		3,2	3,9	4,0	4,0	3,6	2,8	2,5
Mean	Mean PSI	3,4	3,9	3,9	3,9	3,7	2,6	2,3
	IRI (m/km) - SmartIRI	3,06	3,12	3,21	3,59	3,84	5,56	5,01
Standard Deviation and Variation	IRI - SmartIRI	0,29 9%	0,55 18%	0,71 22%	0,49 14%	0,72 19%	1,21 22%	0,40 8%

Table 7 Correlation between PSI and SmartIRI for the teams of Highway CE-501

	Equip 1	Equip 2	Equip 3	Mean PSI and IRI
Correlation	-0,89	-0,89	-0,78	-0,87
R^2	0,79	0,80	0,62	0,76

A strong correlation was verified between the PSI values and the values obtained by the SmartIRI, with the coefficient of determination (R^2) being approximately 0.76. A graph of lines was elaborated to represent the behavior of the indexes under study along the highway, as shown in Figure 5. According to Figure 5, it is observed that as the IRI increases in value, the PSI decreases, confirming the inverse relationship between these two parameters, besides being evidenced by the value of the correlation coefficient, whose value from the means of the indices was -0.87.

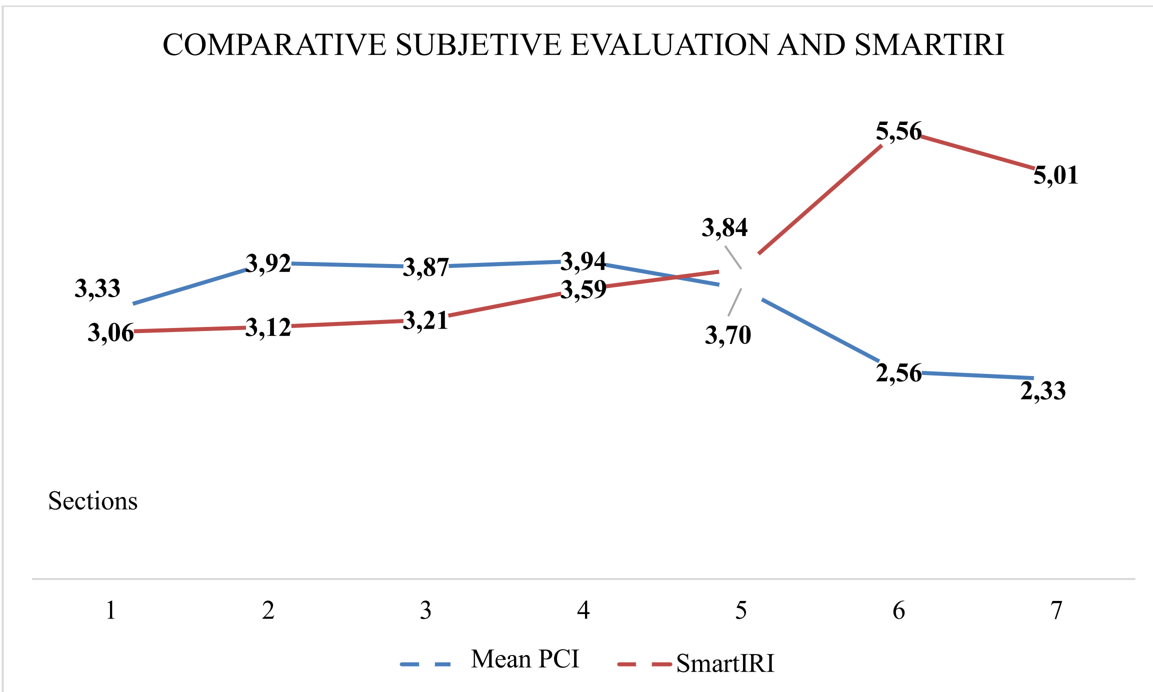

Figure 5 Behavior of the PSI and SmartIRI indices on the CE-501 Highway

The graph of Figure 6 was generated from the data in Table 7, in order to calculate the R^2. A value of 0.76 was obtained indicating a high coefficient of determination. It can also be observed the presence of low irregularity of the highway in the initial stretches (from 1 to 5) and the increase of the irregularity in the final section (6 and 7) of the highway analyzed.

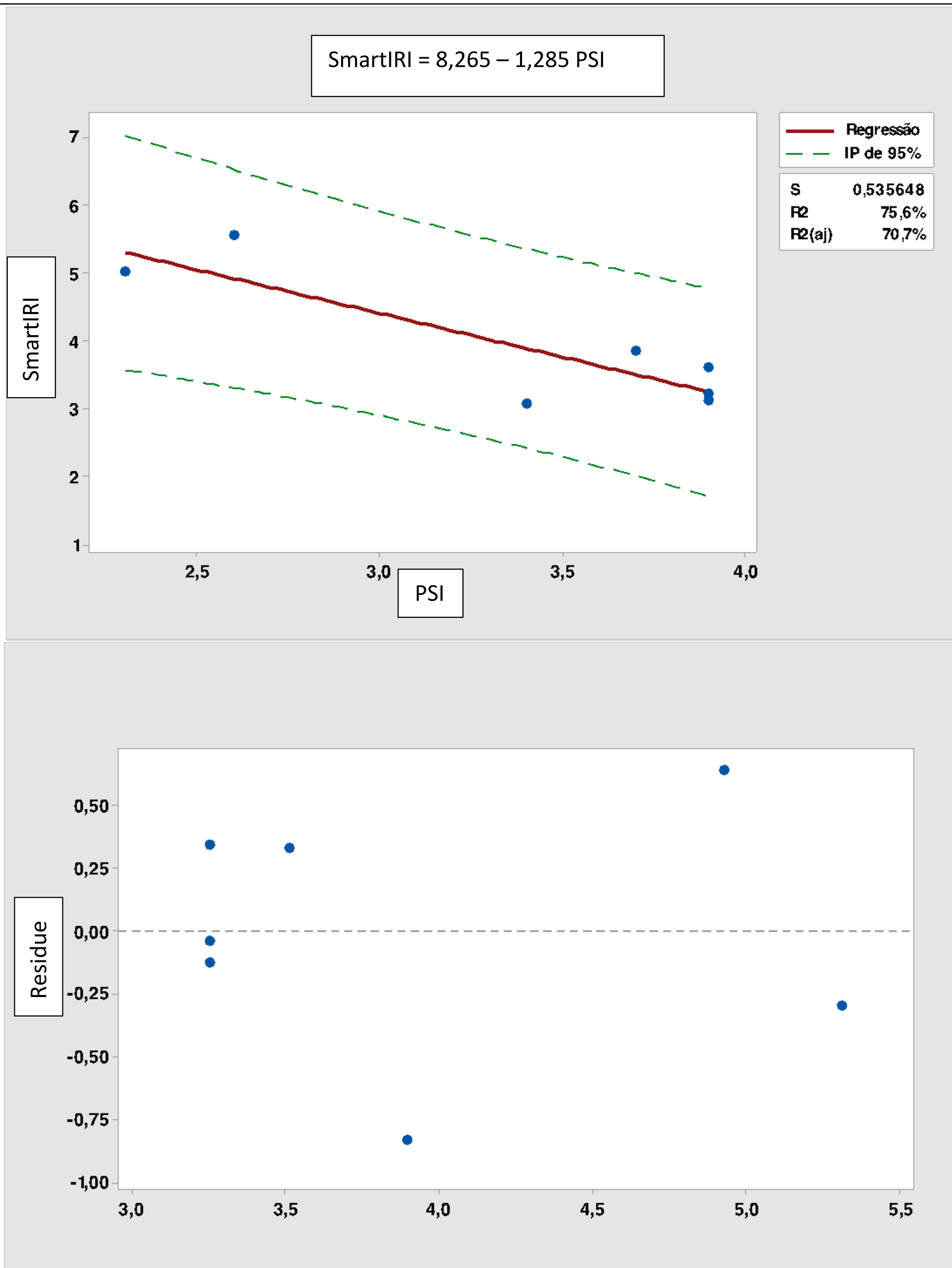

Figure 6 Subjective assessment (PSI) and SmartIRI on Highway CE-501

4.2 Analysis of IRI obtained by SmartIRI by traffic band (year 2019)

Statistically analyzing the data obtained by SmartIRI, it was verified that the traffic ranges have high coefficients of variation, which possibly indicates that the segment is not homogeneous, that is, in some parts of the stretch there is a higher concentration of defects. Table 8 shows the descriptive statistics of the measurements.

Table 8 Descriptive statistics of the measurement performed by SmartIRI on Highway CE-501

Parameters	SmartIRI					
Tracks	P1	P2	P3	P4	P5	P6
Mean – IRI (m/km)	4,00	3,76	4,07	3,62	3,79	3,53
Standard Deviation	1,11	0,83	1,18	0,74	0,82	0,80
Coefficient of variation	28%	22%	29%	20%	22%	23%
Highest value	7,08	5,71	7,70	5,99	6,98	7,09
Lower Valor	2,82	2,70	2,82	2,67	2,98	2,67

Figure 7 shows a part of the section in which the presence of defects such as patches, cracks and holes was observed, possibly contributing to the increase of the IRI value, consequently increasing the coefficient of variation.

Figure 7 Defects observed in segments of Highway CE-501

Analyzing the IRI values in their respective qualitative classes, the indices measured by the application provided the percentages of the sections that are within the qualitative classification according to Table 9.

Table 9 Qualitative data obtained by SmartIRI on Highway CE-501

	SmartIRI (% Qualitative)					
Bands	P1	P2	P3	P4	P5	P6
Excellent	0	0	0	0	0	0
Good	67,57	70,27	70,27	75,68	75,68	84,21
Regular	21,62	29,73	21,62	24,32	21,62	13,16
Bad/Poor	10,81	0	8,11	0	2,7	2,63

Analyzing the evolution of the IRI values obtained by SmartIRI, it was observed that there are no large variations between the measurements (Table 10), indicating that, possibly, maintenance activities were carried out in the section analyzed in order to maintain the highway with the same conditions of rolling comfort.

Table 10 IRI values obtained by SmartIRI - Range P3 on Highway CE-501

	Sections	1	2	3	4	5	6	7
	Intervals (m)	0 to 600	600 to 1200	1200 to 1800	1800 to 2400	2400 to 3000	3000 to 3600	3600 to 4100
IRI (m/km)	Year 2017	3,06	3,12	3,21	3,59	3,84	5,56	5,01
	Year 2019	3,15	3,46	3,63	3,32	3,74	5,90	5,50

Table 11 and Figure 8 show the summary of the survey and the qualitative classification of each index in the P3 traffic band. It should be noted that the measurements are qualitatively correlatable.

Table 11 Summary of survey results on Highway CE-501, in 2017 and 2019

Colors	PSI - 2017 (DNIT, 2003)	SmartIRI - 2017	SmartIRI - 2019
Section 1	3,4 (Good)	3,06 (Good)	3,15 (Good)
Section 2	3,9 (Good)	3,12 (Good)	3,46 (Good)
Section 3	3,9 (Good)	3,21 (Good)	3,63 (Good)
Section 4	3,9 (Good)	3,59 (Good)	3,32 (Good)
Section 5	3,7 (Good)	3,84 (Good)	3,74 (Good)
Section 6	2,6 (Regular)	5,56 (Regular)	5,90 (Regular)
Section 7	2,3 (Regular)	5,01 (Regular)	5,50 (Regular)

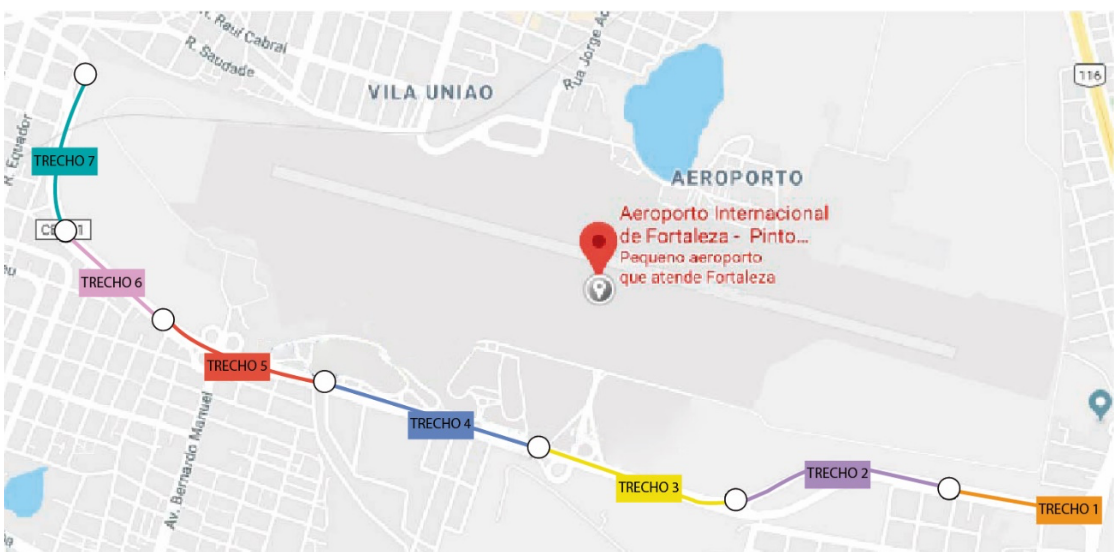

Figure 8 Indication of the sections of Highway CE-501

5. CONCLUSION

Based on the analysis described in this article, it was verified that different types of equipment or methods, belonging to different classes of longitudinal irregularity measurement, can be used to measure comfort to the bearing of flexible pavements, since the two methods used presented correlated values between the indices under study. Based on the data obtained by different methods, it is up to the managers to define the most feasible method to be applied in the decision-making process.

It is also worth noting the efficiency of the SmartIRI for the field survey and the data processing, since it was possible to verify the IRI values in real time, as well as their location on a map, once the application is associated to a System of Geographic Information (GIS). Another point observed is that the use of any of the methods, together with the analysis of the obtained data, can indicate the presence of superficial defects on the road.

Finally, it is concluded that smartphones present themselves with a viable alternative in the preliminary analysis of the functional condition of pavements, since, through the information obtained and the correct analysis of the data, it can help the decision-making of the management team, once its parameters are correlated with traditional methods. These new technologies developed have low cost, easy operation and high productivity, and can be applied on a large scale, emphasizing that more advanced technology does not prevent the use of a more traditional technology.

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