INTERNATIONAL ROUGHNESS INDEX AND RUTTING AT ROAD SECTION IN RN MACEDONIA

МЕЃУНАРОДЕН ИНДЕКС НА РАМНОСТ И БРАЗДЕЊЕ НА ПАТНА ДЕЛНИЦА ВО РС МАКЕДОНИЈА

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Апстракт

Брзиот раст на технологијата овозможува континуирано следење на патните мрежи, па нивното одржување во денешно време е многу важно, прилично лесно и финансиски оправдано. Квалитетот на коловозот може да се оцени според четири карактеристики: рамност на коловозот, оштетувања на коловозот, дефлексии - носивост и отпорност на лизгање. Во овој труд ќе ја разгледаме рамноста на коловозот на автопатот А1 делница: „Неготино - Демир Капија“, лев коловоз - возна лента и лента за престигнување, делница од 121.800 km до 115.220 km во С. Македонија. Ќе го користиме методот IRI за мерење на рамноста на патот. Исто така, измерена е и длабочината на бразда - колотраг на истата патна делница. Се врши статистичка анализа на добиеното мерење и се изведуваат одредени заклучоци.

Клучни зборови

Нерамност на коловозот, Меѓународен индекс на рамност (IRI), бразди, коловозна конструкција.

Abstract

The rapid growth of technology enables continuous monitoring of road networks, so their maintenance nowadays is very important, quite easy and financially justified. The quality of the road pavement can be evaluated by four characteristics: pavement roughness, pavement distress, pavement deflection and skid resistance. In this paper, we are going to consider the pavement roughness of motorway A1 section „Negotino - Demir Kapija“, Left Carriageway – Driving Lane and Fast Lane, section form 121.800 km to 115.220km in N. Macedonia. We are going to use IRI method to measure the road roughness. Also, the Rutting at the same road section is measured. Statistical analysis on the obtained measurement is performed and certain conclusions are derived.

Key words

Pavement unevenness, International Roughness Index (IRI), Rutting, Pavement construction.

1. INTRODUCTION

The main focus of the most of national road agencies in every country, including counties that in development is moving from construction to new roads to maintenance, rehabilitation and improvement of the existing infrastructure. The built infrastructure has influences from the traffic and local environment, contributing into decaying the quality of the originally built road networks.

The accurate information about the current conditions of the whole infrastructure and its remaining service life are crucial for their efficient maintenance. By evaluation of the road network, we can assess the functional and structural conditions of certain road sections. In that way, we can perform routine monitoring or perform specific corrective activities on these sections.

Concerning the functional conditions, they usually refer to quality of driving or safety aspects of road sections (longitudinal and transverse roughness, surface texture and skid resistance, spraying etc). By structural conditions, is usually meant the structural capacity of the roadway, measured by deflection, thickness of the layers and material's properties. Additionally, the visual inspections on the conditions and giving assessments of the roadway's condition can be made. These inspections, unlike others, are qualitative indicators for the observed roadways.

In this paper, we are going to investigate pavement roughness on motorway A1 section Negotino - Demir Kapija, Left Carriageway - Driving Lane and Fast Lane, section from 121+800 km to 115.220 km.

The pavement quality can be evaluated by these four characteristics of pavement condition [1]:

- Pavement roughness (ride ability)
- Pavement distress (surface condition)
- Pavement deflection (structural failure)
- Skid resistance (safety).

By pavement roughness we mean the irregularities in the pavement surface affecting on the smoothness of a ride. This is quite important characteristic, since the World Bank found road roughness to be a primary factor involving the road quality and user cost [2]. It is obvious that the pavement unevenness can cause significant road vehicle dynamic interactions and increases the damage of vehicle and roads and additionally decreases the ride quality [3]. Several techniques can be used to measure the roughness. In our paper we will use the IRI method.

This method was proposed by the World Bank, in Brazil, as a standard statistic correlating and calibrating roughness measurements. The IRI method is used to define a characteristic of the longitudinal profile of a traveled wheel track and establish a standardized roughness measurement. Recommended units for IRI are meters per kilometer (m/km) or millimeters per meter (mm/m). The IRI is determined based on the average rectified slope, i.e. ratio between standard vehicle's accumulated suspension motion (in mm, m) and the distance traveled by the vehicle during the measurement (m, km). The IRI scale versus the ride quality is given in the following table.

Table 1. Pavement roughness versus ride quality

Condition term	**IRI**	**Ride quality**
Very good	< 0,95 m/km	Acceptable 0 – 2,68 m/km
Good	0,95 - 1,49 m/km	
Fair	1,50 - 1,88 m/km	
Poor	1,89 - 2,68 m/km	
Very poor	> 2,68 m/km	Unacceptable

Source: [6]

The longitudinal profilometer is used to measure the pavement longitudinal profile. It uses an accelerometer and an angular-variable differential transformer. This device is a high speed monitoring device and has no impact on the results when moving at speeds from 30 to 120 km/h, so it does not affect traffic speed on any of the road networks [4].

The main components of the longitudinal profilometer are: an accelerometer, an angular-variable differential transformer, an odometer and a laptop computer inside the vehicle.

The working principle of the device is shown in Figure 1

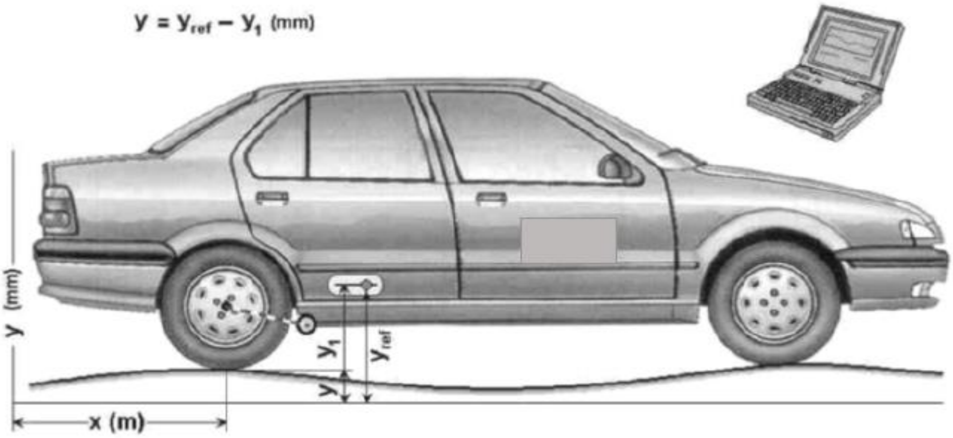

Fig. 1: Working principle of ZAG-VP longitudinal profilemeter
Source: [4]

The accelerometer is fixed in the vertical direction to the sprung mass of the car. The referential electric signal, defines the absolute displacement of the sprung mass as a function of the horizontal distance travelled, is obtained by double integration and filtering of the measured accelerations (a simple GMR inertial reference). An angular-variable differential transformer is fixed on the rear axle of the vehicle (see Figure 2) and is used to measure the angle of the oscillating arm of the rear wheel. The data from this transformer are used to define the vertical distance from the road pavement [5].

While the operator is performing measurements, the longitudinal profile can be monitored. Data processing is performed later in the office and depends on the monitoring purpose: for pavement management purposes, the IRI (International Roughness Index) values are calculated for 20 m and 100 m sample sections in our study.

Fig. 2: Position of the angular-variable differential transformer
Source: [4]

1.1. Factors Affecting Pavement Roughness

In 1986, the Long-Term Pavement Performance (LTPP) project was established as a part of the Strategic Transportation Research Study, which on the other side was initiated in 1980s by Transportation Research Board of the national Research Council, under the support of the Federal Highway Administration, in cooperation of the American Association of State Highway and Transportation Officials. This study was conducted on a large database on pavement characteristics, identifying how pavement performs, behaves and to better understand the factors affecting the pavement performance such as traffic, local environment, construction quality and materials and road maintenance practices.

Factors affecting the pavement roughness are: service life, pavement thickness, traffic levels, subgrade type and maintenance practices. We are going to give a brief description of these factors in the sequel [6]:

- Service Life (SL): Service life if the difference between the last date given at the data and the first date the pavement started working.

- Pavement Thickness (TH): In the LTPP database, the characteristics and thickness for each pavement layer are given. The pavement thickness is calculated using the Asphalt Institute conversion factors. The Asphalt Institute conversion factors determine the equivalent asphalt concrete thickness corresponding to each layer at the pavement structure. These thicknesses can serve as an indication to the strength of the pavement structure. These conversion factors are given in the following table

Table 2. Asphalt Institute Conversion Factors

Description of Layer Material	Conversion Factor
• Native subgrade	0.0
• Granular subbase or base- CBR not less than 20 • Cement modified subbases and bases constructed from low Plasticity Index (PI) soils	0.1-0.3
• Cement or lime-fly bases with pattern cracking	0.3-0.5
• Asphalt concrete surface and base that exhibit extensive cracking and serious deformation in the wheel paths	0.5-0.7
• Asphalt concrete surfaces and bases that exhibit some fine cracking and slight deformation in the wheel paths but remain stable	0.7-0.9
• Asphalt concrete, including asphalt concrete base, generally uncracked, and with little deformation in the wheel paths.	0.9-1.0

Source: [7]

- Subgrade Characteristics (SC): Concerning this characteristics, many test in the framework of this study are conducted on the subgrade and they were recorded in the LTPP database. The subgrade type is determined according to AASHTO classification system, based on the percentage passing sieve number 200 available in LTPP database. The classification is as following: fine subgrade if more than 35% of the samples by weight passes sieve number 200 and coarse subgrade if 35% or less passes sieve number 200.
- Construction Number (CN): This number identifies the changes in the pavement structure generated by rehabilitation treatments or application of maintenance treatments. After the construction of the section, it is assigned a CN of 1. Then, for each maintenance, regardless of its impact on the pavement structure, the construction number is increasing by 1. For example, crack sealing causes a new construction event to be generated, even though significant changes are not caused.
- Traffic Level (TL): The Equivalent Single Axle Load (ESAL) for each state is given in the LTPP database. Here, traffic level is divides into two main categories: low traffic, which is less than 1500 ESAL per lane for a year, and high traffic, which has more than 1500 ESAL per lane for a year.

We note that all of these factors are included into mathematical modeling related to IRI of the pavement. Technique that is used in this mathematical modeling is regression analysis. A single model cannot be applied for all road sections, or generally in all roads from one road network. Regularly, these models are applied on certain road sections classified according to: perception (dry or wet), temperature (low, medium or high), traffic level (low or high) and subgrade type (coarse or fine).

A common problem in roads is Rutting. Rutting is creation of depression or a groove and typically shown as wheel path engraved on the road structure. Its precise definition in civil engineering is permanent deformation or consolidation that accumulates in asphalt pavements overtime.

Fig. 3: Rutting in a motorway in Sweden

The rutting failure in flexible pavement is not because of the vehicle on the road, but it occurs as a structural incompetence.

There three main causes of rutting in asphalt:

- Problems in asphalt concrete layer
- Problem in structural layer
- Weak subgrade foundation.

Rutting is more possible on road sections that lack compaction, have insufficient thickness of layers and has weak asphalt mixtures. Also the quality of execution of work (asphalt rolling, thickness of the base, amount of aggregate in the hot-mix asphalt (HMA)), seasonal changes (during summer, the flexible asphalt road starts losing binder content result, asphaltic binder starts to stick on tires resulting to aggregate and binder in asphalt to move sideways), improper compactification (it should be used Field Density Tests (FDT)), improper thickness of base (the road is more prone to rutting if the subbase thickness is not sufficient), improper mix design (poor mix results in rutting), excessive amounts of asphalt and use of stiff asphalt binder (the binder should be picked in correlation with temperature requirements in order to access the performance in the particular temperature).

Depending on the cause of rutting, the rutting can be classified in three categories [8]:

- Mix design rutting: occurs when the subgrade is intact yet the pavement shows grooves and wheel path. The depressions and the rutting is a result of improper mix design. The symptoms of mix rutting include raised elevation on the edges of the wheel path
- Subgrade rutting: Subgrade not only give a sturdy support to the flexible pavement but also prevents distresses like rutting. If not proper compactification is not applied on the subgrade, it can settle under repeated loading resulting into ruts. Subgrade rutting shows a distinctive cracked asphalt surface. The cracks allow the pavement to flex into the subgrade rut.
- Densification: This rutting results in improper compaction of the top asphaltic base or wearing course. As there was a room for compactification, the asphalt continues to compact under traffic loading. Densification usually happens on brand new paved surfaces.

The rutting on roads results with the following:

- The entire structure of the roads is compromised by rutting. As a result of depressions and grooves, water can find a way to stay in those depressions resulting in hydroplaning
- Rutting can cause drivers to stumble along the road shoulder and increase the chances for traffic accidents
- Replacing roads that possess ruts is serious financial setback. Sometimes it is required replacement of the subbase along with the sections of the road having ruts. If only top wearing surface is replaced, the subbase will again damage the newly paved road.
- Problems like rutting, potholes or cracking when combined can result in substantial maintenance costs

2. METHODOLOGY AND STATISTICS BACKGROUND

Preparation of datasets of the point load test values according different criteria was supported by means of GIS tools and spreadsheet program. The data was classified according rock type, geotectonic unit, anisotropy, depth of samples, unit weight, etc. In the present paper, the attention is purely on the point load test results.

In this section we will present some of the notations and methods in Statistics, which are going to be used later. The mean of the sample is defined as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

where $x_1, x_2, ..., x_n$ are observed values in the sample.

The formal version of the midpoint is the median. The median *M* is the midpoint of a distribution, described as a number satisfying that the half of observations is smaller and the other half are larger than *M*.

As a remark we can say that the mean and the median of a roughly symmetric distribution are close together. If the distribution is exactly symmetric, the mean and the median are exactly the same. In a skewed distribution, the mean is usually farther out in the long tail than is the median.

Skewness is a measure of symmetry, or precisely, the lack of symmetry. A distribution, or data set, is symmetric if it looks the same to the left and right of the center point.

If the skewness is between -0.5 and 0.5, the data are fairly symmetrical. If the skewness is between -1 and – 0.5 or between 0.5 and 1, the data are moderately skewed. If the skewness is less than -1 or greater than 1, the data are highly skewed.

Kurtosis is a measure of whether the data are heavy-tailed or light-tailed to a normal distribution.

For kurtosis, the general guideline is that if the number is greater than +1, the distribution is too peaked. Likewise, a kurtosis of less than –1 indicates a distribution that is too flat.

Concerning the seeking for a correlation among two variables we stress the following notations and relations. If we think that a variable *x* may explain or even cause changes in another variable *y*, we call *x* an explanatory variable and *y* a response variable.

Let we have data of an explanatory variable *x* and a response variable *y* for *n.*

The least-squares regression line is given with the equation $y = a + bx$, with a slope

$$b = r\frac{s_y}{s_x} \tag{2}$$

where s_x, s_y are standard deviations of the variable *x*, *y*, respectively and *r* is their correlation. The interception a is calculated by

$$a = \bar{y} - b\bar{x} \tag{3}$$

where $\bar{x}, \bar{y}$ are means of the variables *x*, *y*, respectively.

With this regression line we obtain the predicted response *y* for any *x*.

There is a close connection between correlation and the slope of the least-squares regression line. The slope and the correlation always have the same sign.

The correlation *r* describes the strength of a straight-line relationship. This description takes a specific form: the square of the correlation, r^2, is the fraction of the variation in the values of *y* that is explained by the least-squares regression of *y* on *x*. The last one can be briefly written as:

$$r^2 = \frac{\text{var}\,iation\ \ in\ \ y\ as\ x\ \ pulls\ it\ along\ the\ line}{total\ \ \text{var}\,iation\ in\ observed\ \ values\ of\ \ y}. \tag{4}$$

From the last one, it is clear that we can always find a regression line for any relationship between two quantitative variables, but the usefulness of the line for prediction depends on the strength of the linear relationship. Hence, r^2 is almost as important as the equation of the regression line.

The 95% confidence interval is a range of values that you can be 95% confident contains the true mean of the population. As the sample size increases, the range of interval values will narrow, meaning that you know that mean with much more accuracy compared with a smaller sample. Here, the 95 % confidence intervals can be formed (read from the tables below) by (mean-confidence level (95.0%), mean+confidence level (95.0%)).

3. ANALYSIS

Here we are going to analyze the obtained data using the statistical tools presented in the previous section. We are going to present the results about pavement roughness (IRI) and rutting on motorway A1 section „Negotino - Demir Kapija“, Left Carriageway - Driving Lane and Fast Lane, section from 121+800 km to 115+220km. The length of the section is 6,576 km. The measurements are made on every 20 meters and 100 meters, therefore obtained results for IRI and Rutting at every 20 meters are denoted by IRI 20 and Rutting 20, and obtained results for IRI and Rutting at every 100 meters are denoted by IRI 100 and Rutting 100.

First we present the obtained results on Driving Lane (DL), IRI 100 (m/km) IRI 20 (m/km) and Rutting 20 (mm), Rutting 100 (mm). The obtained measurements are placed in the following tables: Carriageway

Table 3. IRI 100 (m/km) Driving Lane (DL)

IRI (100)	Minimum	Average	Maximum	St.Dev	80%	95%	num of data	sample length (km)
	0.54	1.10	5.54	0.76	1.23	1.29	66	6.576

Table 4. IRI 20 (m/km) Driving Lane (DL)

IRI (20)	Minimum	Average	Maximum	St.Dev	80%	95%	num of data	sample length (km)
	0.41	1.10	10.50	0.94	1.17	1.21	329	6.576

Next, we give basic statistic characteristics for the obtained measurements about the IRI and Rutting on the investigated road section:

Table 5. Statistic characteristics for IRI 20 and IRI 100 (m/km) for Driving Lane (DL)

IRI 20 DL(m/km)	
Mean	1.103524
Standard Error	0.051901
Median	0.89
Mode	#N/A
Standard Deviation	0.941402
Sample Variance	0.886238
Kurtosis	40.81337
Skewness	5.485382
Range	10.0865
Minimum	0.41475
Maximum	10.50125
Sum	363.0595
Count	329
Confidence Level(95.0%)	0.102101

IRI 100 DL(m/km)	
Mean	1.103029
Standard Error	0.094374
Median	0.91525
Mode	#N/A
Standard Deviation	0.766697
Sample Variance	0.587824
Kurtosis	19.05241
Skewness	4.018861
Range	4.99585
Minimum	0.5439
Maximum	5.53975
Sum	72.7999
Count	66
Confidence Level(95.0%)	0.188478

Table 6. Statistic characteristics for Rutting 20 and Rutting 100 (mm) for Driving Lane (DL)

Rutting 20 DL(mm)	
Mean	0.679486783
Standard Error	0.014651726
Median	0.64625
Mode	0.6825
Standard Deviation	0.265758239
Sample Variance	0.070627441
Kurtosis	11.98320552
Skewness	2.639824074
Range	2.2325
Minimum	0.14
Maximum	2.3725
Sum	223.5511515
Count	329
Confidence Level(95.0%)	0.02882321

Rutting 100 DL(mm)	
Mean	0.679763742
Standard Error	0.029000086
Median	0.64675
Mode	#N/A
Standard Deviation	0.235597813
Sample Variance	0.05550633
Kurtosis	14.40210097
Skewness	3.086872135
Range	1.686502513
Minimum	0.299497487
Maximum	1.986
Sum	44.86440699
Count	66
Confidence Level(95.0%)	0.057917171

On the next two graphs, a comparison between IRI 100 and IRI 20, and Rutting 20 and Rutting 100 is given. The results are expected, i.e. we can notice bigger oscillations in the case where measurements are made on 20 meters, either in case of IRI or Rutting, corresponding to more precise measuring in IRI 20.

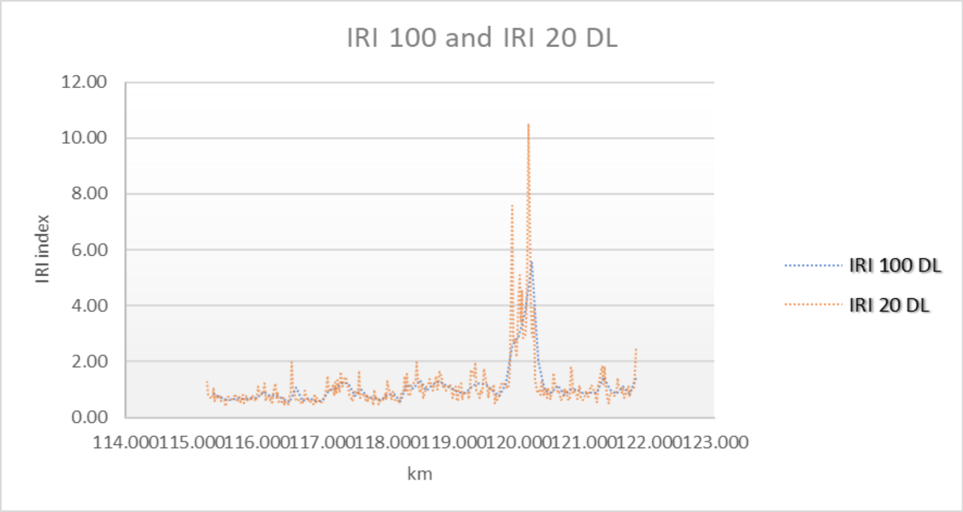

Fig. 4: Comparison between IRI 100 and IRI 20 in DL

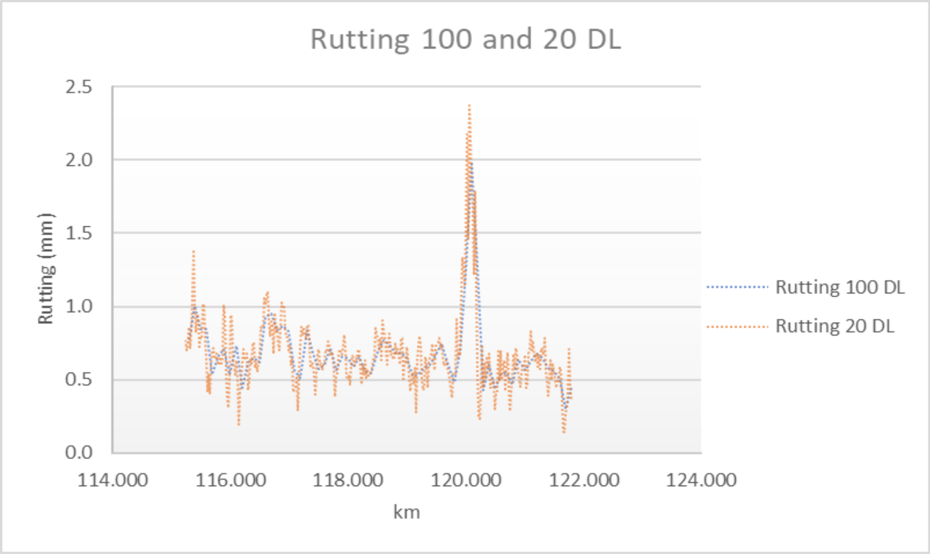

Fig. 5: Comparison between Rutting 100 and Rutting 20 in DL

From the performed regression analysis, we can say that there is no correlation between IRI 100 and Rutting 100. Also there is no correlation between IRI 20 and Rutting 20 in the Driving Lane Lane.

In the sequel, we present the results from the measurements at the Fast Lane at the investigated road section. The basic statistics are given as follows:

Table 7. IRI 100 (m/km) Fast Lane (FL)

IRI (100)	Minimum	Average	Maximum	St.Dev	80%	95%	num of data	sample length (km)
	0.59	1.25	7.76	1.07	1.42	1.51	66	6.576

Table 8. IRI 20 (m/km) Fast Lane (FL)

IRI (20)	Minimum	Average	Maximum	St.Dev	80%	95%	num of data	sample length (km)
	0.43	1.25	12.32	1.24	1.34	1.38	329	6.576

Next, we give basic statistic characteristics for the obtained measurements about the IRI and Rutting on the investigated road section:

Table 9. Statistic characteristics for IRI 20 and IRI 100 (m/km) for Fast Lane (FL)

IRI 20 FL(m/km)	
Mean	1.249098
Standard Error	0.068214
Median	0.956
Mode	#N/A
Standard Deviation	1.237287
Sample Variance	1.530879
Kurtosis	31.37435
Skewness	5.061617
Range	11.89425
Minimum	0.43
Maximum	12.32425
Sum	410.9531
Count	329
Confidence Level(95.0%)	0.134192

IRI 100 FL(m/km)	
Mean	1.248126
Standard Error	0.132722
Median	0.9853
Mode	#N/A
Standard Deviation	1.078239
Sample Variance	1.1626
Kurtosis	23.44315
Skewness	4.567521
Range	7.17765
Minimum	0.58595
Maximum	7.7636
Sum	82.37635
Count	66
Confidence Level(95.0%)	0.265064

Table 10. Statistic characteristics for Rutting 20 and Rutting 100 (mm) for Fast Lane (FL)

Rutting 20 FL(mm)	
Mean	0.61551893
Standard Error	0.034702351
Median	0.46625
Mode	#N/A
Standard Deviation	0.629443629
Sample Variance	0.396199283
Kurtosis	15.808852
Skewness	3.552482166
Range	5.20375
Minimum	0.005
Maximum	5.20875
Sum	202.505728
Count	329
Confidence Level(95.0%)	0.068267256

Rutting 100 FL(mm)	
Mean	0.614856
Standard Error	0.070822
Median	0.490602
Mode	#N/A
Standard Deviation	0.575364
Sample Variance	0.331044
Kurtosis	11.31598
Skewness	3.252415
Range	3.039
Minimum	0.09625
Maximum	3.13525
Sum	40.58047
Count	66
Confidence Level(95.0%)	0.141442

Similar like in the case of DL, a comparison between IRI 100 and IRI 20, and Rutting 20 and Rutting 100 is given. The results are the same, i.e. in both cases, we can register bigger oscillations in the case where measurements are made on 20 meters.

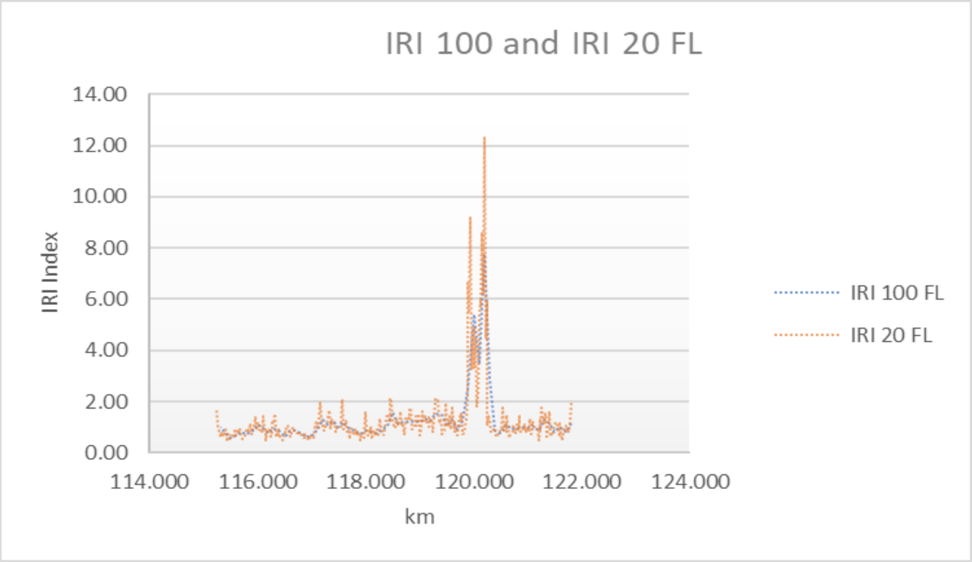

Fig. 6: Comparison between IRI 100 and IRI 20 in FL

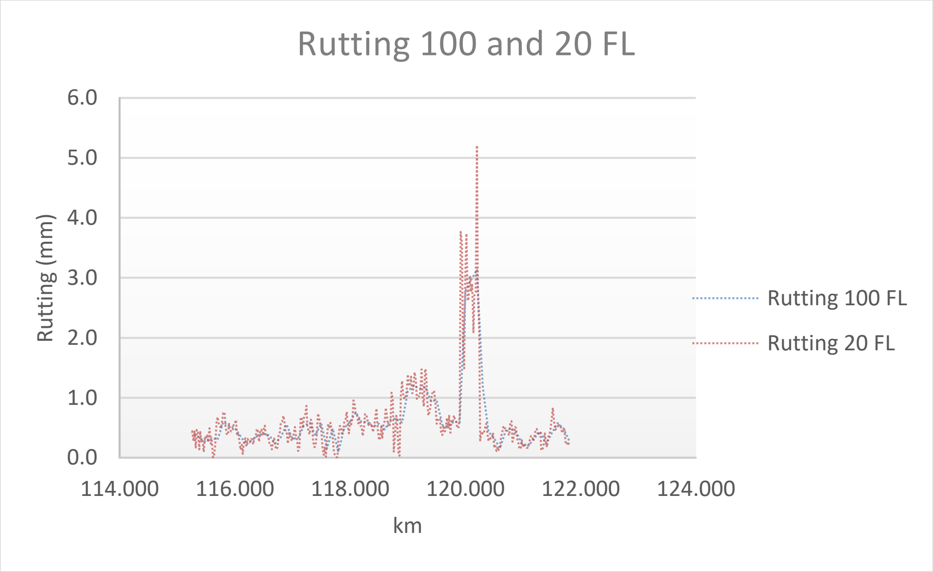

Fig. 7: Comparison between Rutting 100 and Rutting 20 in FL

From the performed regression analysis, we can say that there is correlation (lower threshold) between IRI and Rutting. This correlation is stronger where measurements are made in each 100 meters. As a result, in point view of mathematics this is an expected result. The correlations are given in the following two figures:

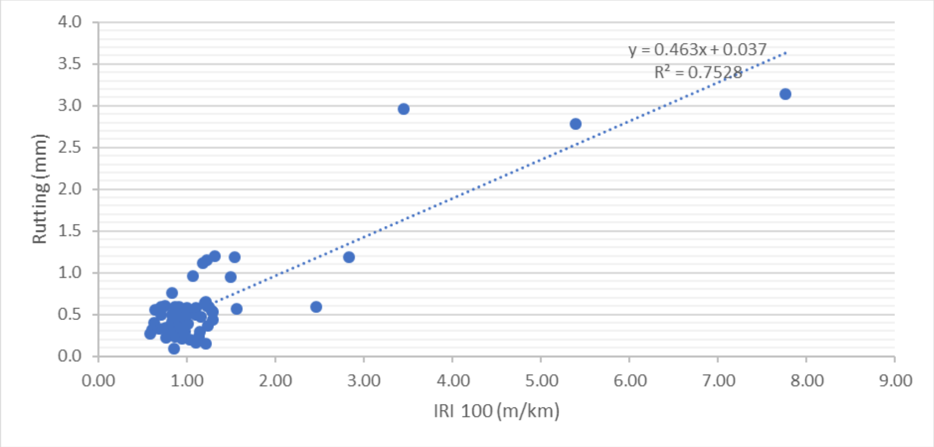

Fig. 8: Correlation between IRI 100 and Rutting 100 at Fast Lane (FL)

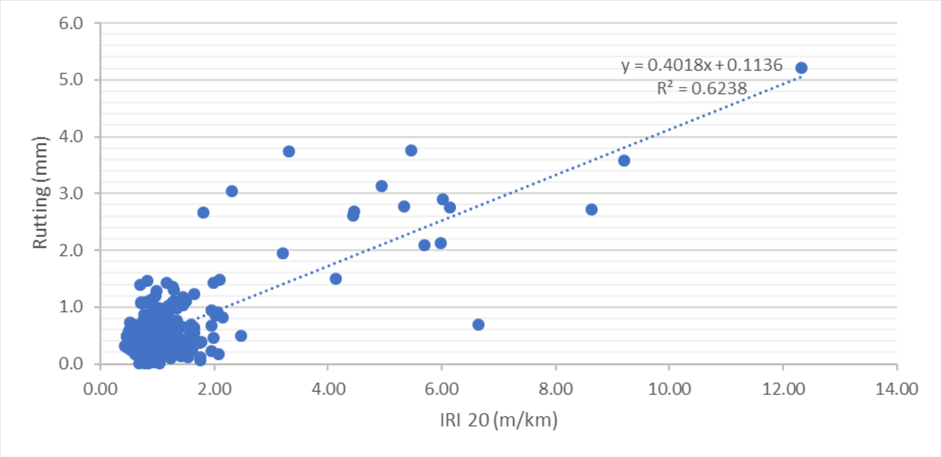

Fig. 9: Correlation between IRI 20 and Rutting 20 at Fast Lane (FL)

4. CONCLUSIONS

The Roughness of pavement has been universally accepted as a measure of functional condition of a pavement. It constitutes the smoothness and frictional properties of the pavement surface and in turn is related to the safety, and the ease of the driving path. It is determined using the international roughness index (IRI), which is a measure for texture of the pavement surface, and also depends on the amount of other functional distresses present on the road surface.

There so many causes of pavement unevenness and rutting. They can be prevented with good construction practices and avoiding settlement. Even though we have got innovative compaction technology at hand, rutting is still a challenge for transportation engineers. Therefore, it is a dire need to improve industry standards and ensure quality control.

Longitudinal profilometer should be more frequently used and for all three reasons: quality control, management and research. Descriptive statistics can give quantitative measures of the current condition of the pavement, and based on that and given standards, it can be planned activities, such as maintenance of observed road sections. As a conclusion, the measuring is more reliable if the measuring points are on smaller distance. There is a good correlation between IRI and Rutting in the Fast Lane, in comparison with Driving Lane. This correlation is especially good correlation, when measuring is on each 20 meters. Based on this research, we can say that as far we decrease the distance between measuring points, we can expect better correlation between IRI and Rutting. More important, this correlation occurs, only when the values of IRI pass certain upper threshold.

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