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Research Paper

# LTTP Data Analysis: Factors Affecting Pavement Roughness for the State of California

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ABSTRACT

The contributions of pavement structure and features, rehabilitation techniques, climatic conditions, traffic levels, layer materials and properties, pavement distress, and other factors causing changes in pavement smoothness are not well documented. As a result, it becomes difficult to select the appropriate pavement structure, design features and rehabilitation strategies to ensure pavement smoothness. This study focuses on analysing the available LTPP data for asphalt pavements in California by investigating the correlation between the pavement roughness and the effect of pavement temperature, precipitation, fatigue, age of pavement, rutting, and the average annual daily truck traffic. IRI has been identified as the factor characterizing pavement smoothness. Results indicated that when diving pavement sections between three different groups according to the annual precipitation for pavement section in the State of California, the $IRI_{change}$ can be predicted with 93.5% accuracy for sections with less than 200mm of annual precipitation, 85.9% accuracy for sections with annual precipitation between 200mm and 90mm, and 90.1% for sections with annual precipitation higher than 900mm.

## 1 Introduction

Traffic had a massive increase in the past few years, this increase resulted in a decrease in the pavement service life, resulting in a need for studies to identify new and different methods of rehabilitation and maintenance techniques to increase the pavement service life. Pavement smoothness has been recognized as the one of the factors characterizing pavement performance. Pavement smoothness or roughness can be expressed in terms of surface irregularities that affect the ride quality. However, the contributions of pavement structure, traffic levels, pavement distress, and other factors to changes in pavement smoothness are not well documented. As a result, it becomes difficult to select the appropriate pavement structure, design features and rehabilitation strategies to ensure pavement smoothness. This study focuses on analysing the available data for asphalt pavements in California to provide preliminary conclusions regarding the factors that affect pavement smoothness. Previous study conducted by Perera and Kohn [1, 2] has been used as reference for this study. Perera and Kohn

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used determined parameters such as: age, temperature, precipitation, average annual daily truck traffic (AADTT), rutting, and fatigue, in order to relate its effect with International Roughness Index (IRI). Age is taken from the date of construction to the date of first rehabilitation. Precipitation and temperature are taken from the average annual temperature and average annual precipitation. Rutting is the pavement distress that occurs when there is a depression, or a groove worn through the wheel path due to wheel load, and it is measured in mm. Shear occurs at the side of the rut. Fatigue cracking occurs due to repeated loading in the pavement, and it is measured in $m^2$.

## 2 Literature Review

With the objective to evaluate traffic data and different pavement sections, the Long-Term Pavement Performance (LTPP) [3] program was started in 1984. The LTPP data is available at the InfoPave website, with over 2000 pavement test sections. Roughness data is one of the available data. It is very important to analyse and understand what factors are affecting the road roughness, since it will provide important comprehension on how a particular pavement will behave according to a certain level of traffic and weather conditions. It is important to understand this correlation, since it can lead to huge pavement design improvements, considering that the pavement type could be selected according to the lowest deterioration rate.

Roughness was defined by Sayers et al. [4] as “the variation in surface elevation that induces vibrations in traversing vehicles” or in other words, how bumpy or smooth the road is, since the bumpy sensation can be caused by rough pavements. One of the primary factors that affects the pavement smoothness is International Roughness Index (IRI). IRI is the measure for texture of pavement. Gillespie et al. [5] published roughness measuring guidelines in 1980. Sayers et al. [3] established the IRI in 1982, as an internationally accepted parameter to monitor roadway smoothness and irregularities.

Several studies [6, 7] have shown that smooth roads costs highway agencies less over the life cycle of the pavement, thereby decreasing the overall cost of maintaining the roadway in addition to user operating costs, delay costs, and fuel consumption. IRI is measured using specialized vehicles with computer technology to monitor pavement roughness. These vehicles record the displacement of the vehicle chassis, which is located on the rear axle, usually in terms of irregularities per mile or foot [6].

The Louisiana Department of Transportation and Development uses the California-Type Profilograph as the device to measure the pavement profiles. This process works by pushing the profilograph into the pavement surface and recording the pavement longitudinal profile on paper, the trace is then analysed with a 5.1 mm blanking bandwidth to determine the profile index. The usage of the profile index brings concerns considering the fact that using the 5.1 mm blanking bandwidth, $PI_{5.1}$, results in filtering parts of the pavement roughness, showing smoother pavements than in reality. Those concerns increased the search of pavement smoothness acceptable measures, which due to the increase in technology and equipment, stablished the IRI as the pavement smoothness rational measurement. As a rational method, IRI reflects the pavement smoothness and the pavement ride quality [8]. In order to assist state highway departments to stablish new smoothness specifications, research studies have been focusing on developing correlations between the old and new pavement smoothness indicators. Morels are now being used to predict the IRI value using the $PI_{5.1}$ profile index from manual or computerized profilographs, ultrasonic–type inertial profilers, lightweight inertial profilers, and laser-type inertial profilers. These models were developed based on data collected from specific climatic regions, using specific equipment, and specific pavement type [9-11].

In order to study the correlation between pavement performance and the combined effects of environment, traffic load, pavement age, and pavement maintenance, Al-Suleiman [12] showed a direct correlation between pavement age and pavement serviceability for highway sections that presented similar traffic volumes. Pavements were divided into three different age groups, where Age Group I included pavements that are either fairly new (5 years) or it has been less than 5 years since last major repairs/improvements have been made. These pavements are in very good condition with respect to surface roughness and do not require maintenance works; Age Group II contained pavements in good to fair condition and of age between 5 to 15 years of reconstruction or major maintenance works. Pavements on this group require increasingly more frequent routine maintenance with time. Effectiveness of maintenance is highest for pavements in this group; Finally, Age Group III contained pavements in poor condition. Pavement age may range from 10 years to more than 15 years. Major improvement or resurfacing of the pavement is much more needed than routine maintenances. From this classification it is clear that the pavement age is a major factor when it comes to determining pavement smoothness. Therefore, the effect of age of pavement on pavement smoothness needs to be considered.

Rutting is the pavement permanent deformation resulted from frequent repetition of heavy axle loads, for this reason rutting is one of the major concerns in pavement design. Rutting is also known for its gradual increase with the increase of the load repetitions, appearing as longitudinal pavement depressions located at the wheel path. Two main reasons are the main cause of concerns from rutting: With the creation of depressions in the pavement surface, the water gets trapped in the pavement impervious surfaces, creating a hazardous situation with vehicles hydroplaning, but also increasing the formation of potholes. The second reason is that as the ruts progress in depth, the difficulty into steering increases, leading to safety concerns. Hence, it is safe to say that rutting has significant effect on pavement performance [13]. Therefore, if the effect of different factors on pavement smoothness is to be studied, it is important that rutting, a factor that highly determines the serviceability of pavements, be also be considered in the study. The mechanism of rutting in paving materials develops gradually, and it is caused by a decrease in volume, and hence increase in density, and shear deformation, occurring in any of the pavement layers, and sometimes at the subgrade. Hofstra and Klomp indicated that shear deformation was the main rutting mechanism [14].

The ability to withstand repeated bending loads without fracturing by an asphalt mix is called fatigue resistance. It manifests itself in the form of cracks after repeated traffic loads. The usage of repeated flexure, diametral tests, or direct tension tests with different stress or strain levels determines the fatigue characteristics of the asphalt mixes when analysing the relationship between initial stress and strain to the number of load repetitions to failure [15]. Hence, fatigue has been identified as another parameter whose effect of pavement smoothness needs to be studied.

Millions of dollars in pavement maintenance costs every year are associated with transverse cracking caused by temperature stresses. The now known term “low-temperature cracking” was once believed as the only cause of temperature induced transverse cracking. “Thermal-Fatigue Cracking” is the mechanism that accounts for relatively moderate temperatures that induces asphalt pavements cracking, due to temperature cycling that results in the fatigue resistance of the pavement being exceeded [16]. Therefore, it seems clear that temperature plays an important role in the performance of asphalt pavements, and it is reasonable to assume that it also have some effect on pavement smoothness. Therefore, the effect of temperature on the smoothness of pavement will also be explored in this report.

Lu and Zhang [17] stated that truck traffic is the leading factor to pavement damage and deterioration, also affecting the pavement texture. Truck traffic is traditionally measured by the equivalent repetition of a standard axle load (ESAL). Due to the recent advance in technology, new pavement distress models and sophisticated test equipment’s have advanced the pavement design to the mechanistic-empirical procedures. Since 1987, the California Department of Transportation (Caltrans) has been installing Weigh-In-Motion (WIM) stations and has been collecting truck traffic data on state highways. Microscopic-level examination of truck traffic data can provide important insights into traffic flow patterns and into generating accurate estimation of growth rate for Mechanistic-Empirical Pavement Design Guides (MEPDG) users to back-cast data for existing pavement sections performance predictions. For this reason, AADTT was included as one of the parameter in this study.

Water is also a natural factor causing pavement damages, since it can change the local moisture content, reduce the pavement strength, and increase the extent and severity of cracks and potholes. Water also accelerates the pavement performance deterioration, shortening the pavement life. John and Zhou [18] used unsaturated seepage theory to analyse the progress and rules of rainfall infiltration in pavements. Since water causes significant damage in the pavement, the effect of rainfall on the pavement smoothness will also be taken into consideration.

## 3 Data Collection

The objectives of this research was to analyse and understand the effect of different factors into the pavement roughness, for this reason, the effect of age, climate, traffic and pavement distresses factors on the IRI values were studied using various approaches. The data was then used to perform a regression analysis to obtain the relation between the study parameters and IRI. The data used in this research was obtained from the Long-Term Pavement Performance (LTPP) database [3]. The asphalt pavement sections of California were chosen for study in this paper. A review of LTPP database was conducted to filter the sections required for study. After literature review of different reports, the parameters required for study were chosen and their availability for the sections in LTPP database was checked. The parameters International Roughness Index (IRI), age of pavement, annual average precipitation, annual average temperature, AADTT, fatigue and rutting distress in the pavement sections were chosen for study. After filtering the data for required study parameters, a total of 63 pavement sections were selected, for a total of 71 observations. Fig. 1 shows the sections chosen for study. The red marks denote the sections that are not being monitored anymore by the LTPP, while the green marks show the sections that are still under monitoring by the LTPP. The values of different parameters for these sections were then extracted from the LTPP database. The effect of these parameters on IRI was then studied using multiple regression analysis and scatter plots.

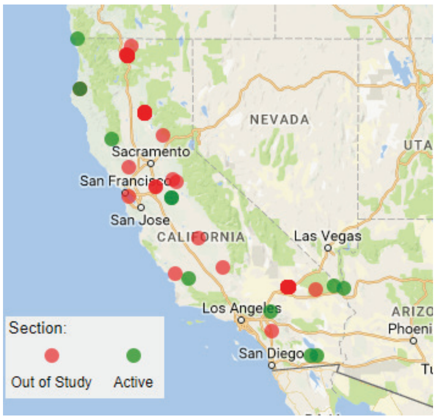

*Fig. 1 – Sections chosen for study [1]*

## 4 Data Analysis

### *4.1 Effect of age of pavement*

Age vs. IRI graph was plotted for the study sections to observe the variation in the $IRI_{change}$ with the age of the pavements. $IRI_{change}$ is the difference between the $IRI_{initial}$ and the $IRI_{final}$. The $IRI_{change}$ values show that the roughness increases with time in the absence of any treatment of rehabilitation works, showing the smoothness of pavement decreases with time. Fig. 2 shows the increasing trend of IRI with age.

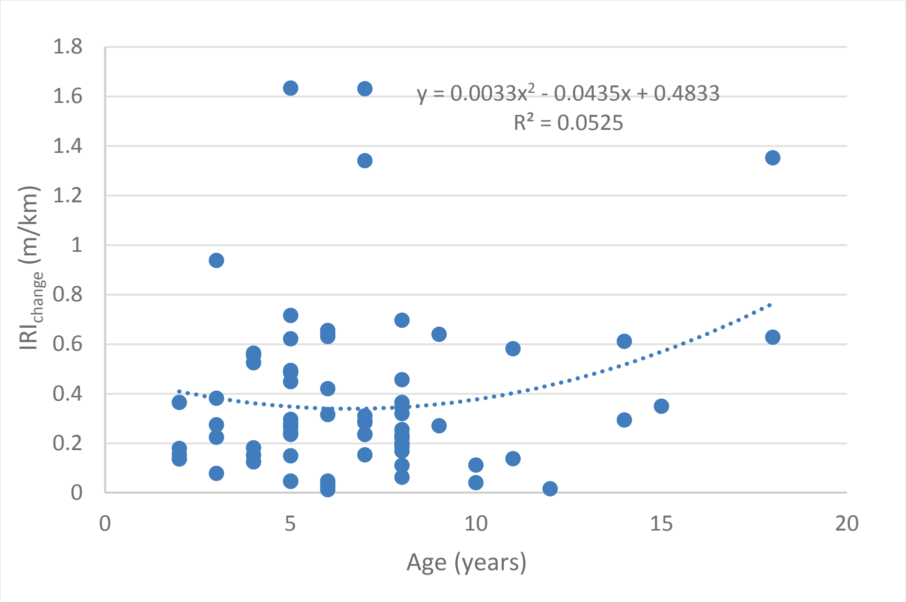

*Fig. 2 – Age vs $IRI_{change}$ for sections*

### *4.2 Effect of Temperature*

Temperature vs. IRI graph was plotted for the study sections to observe the variation in IRI with corresponding average annual temperatures. As shown in Fig. 3, IRI tends to increase with the increase of the annual average temperature, however, the noticed $R^2$ was 0.0988, indicating that the temperature is not the only factor influencing the increase in the pavement roughness.

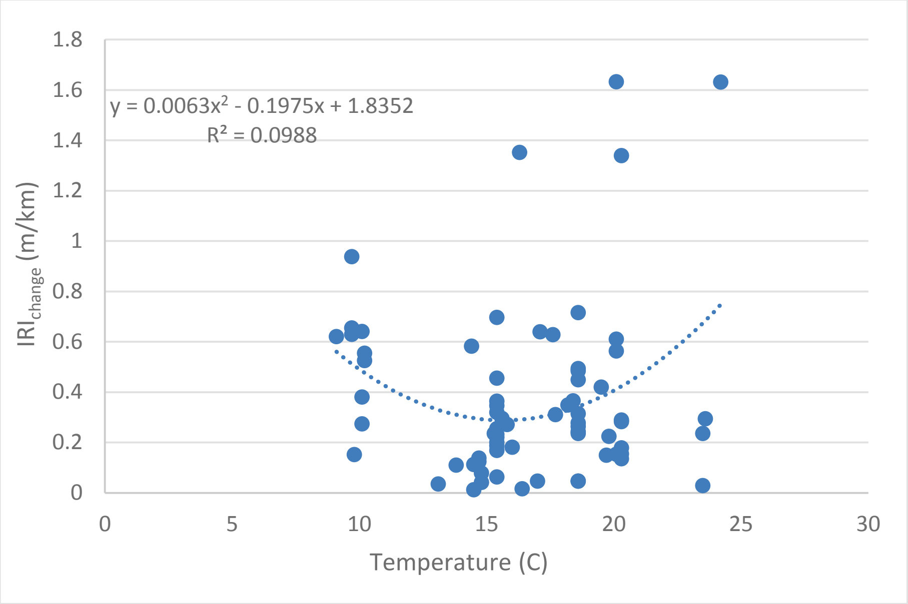

*Fig. 3 – Annual Average Temperature vs $IRI_{change}$*

### *4.3 Effect of precipitation*

Precipitation vs. IRI graph was plotted for the study sections to observe the variation in IRI with corresponding average annual precipitation. The effect of precipitation on IRI is not very pronounced with sections showing no clear increase or decrease in IRI with respect to precipitation. This, along with the very low value of coefficient as shown in Fig. 4, has led to the conclusion that there is no significantly direct relationship between pavement smoothness (IRI) and annual average precipitation.

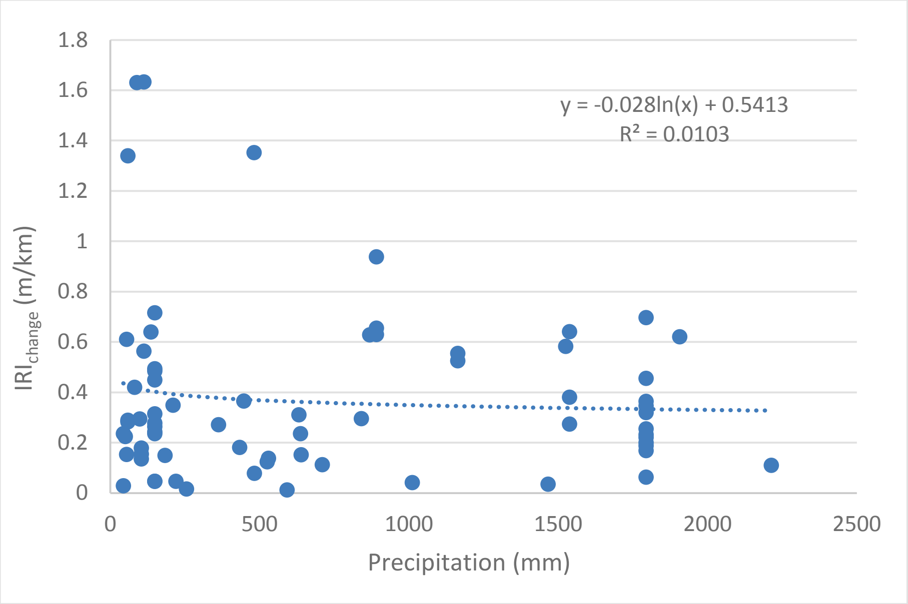

*Fig. 4 – Annual Average Precipitation vs $IRI_{change}$*

### *4.4 Effect of average annual daily truck traffic (AADTT)*

AADTT vs. IRI graph was plotted for the study sections to observe the variation in IRI with corresponding AADTT for the pavement section. The IRI values does not seem to show an increasing trend with increase in AADTT in the absence of any treatment of rehabilitation works. Fig. 5 shows the variation of IRI with AADTT. The low value seems to suggest that there isn't a significantly direct relationship between IRI and AADTT.

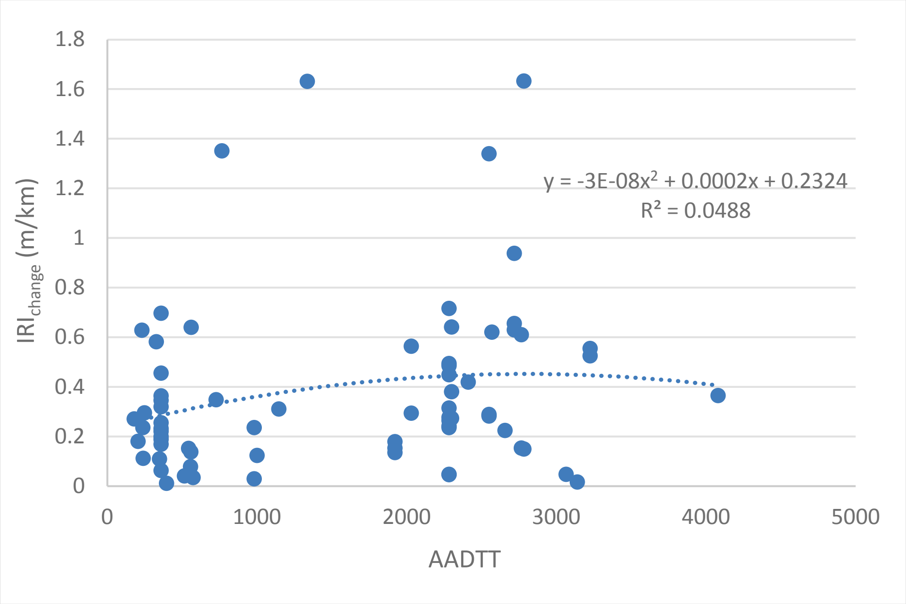

*Fig. 5 – Annual Average Truck Traffic vs IRI$_{change}$*

### *4.5 Effect of Rutting*

Rutting vs. IRI graph were plotted for the study sections to observe the variation in IRI with corresponding rutting of the pavement section. The IRI values show an increasing trend with increase in rutting in the absence of any treatment of rehabilitation works (Fig. 6). Observed $R^2$ of 0.349 indicates that rutting has a higher influence than other factors compared on this paper.

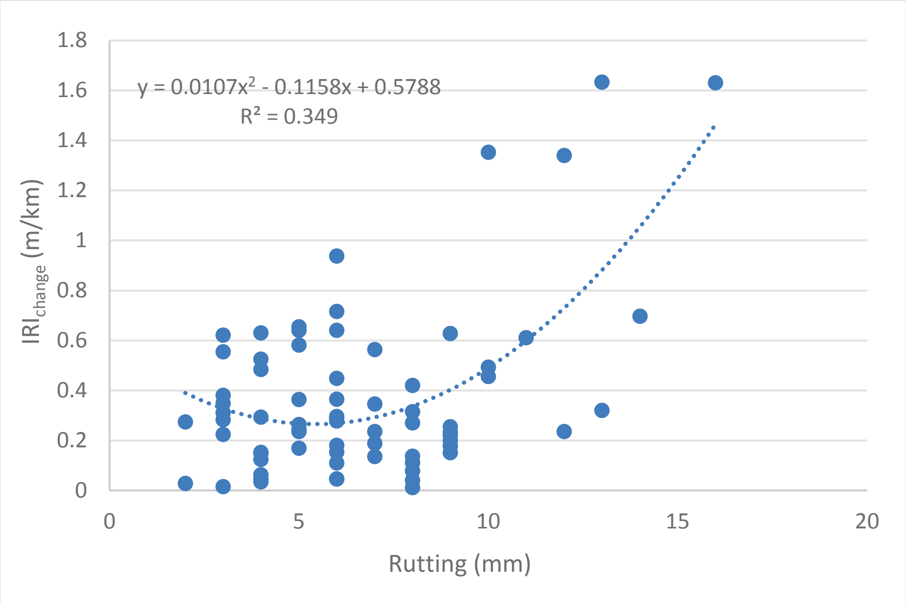

*Fig. 6 – Rutting vs IRI$_{change}$*

### *4.6 Effect of Fatigue*

The last factor to be compared is Fatigue vs. IRI, where a graph was plotted for the study sections to observe its effect on pavement smoothness. The IRI values show a small increasing trend with increase in fatigue in the absence of any treatment of rehabilitation works (Fig. 7).

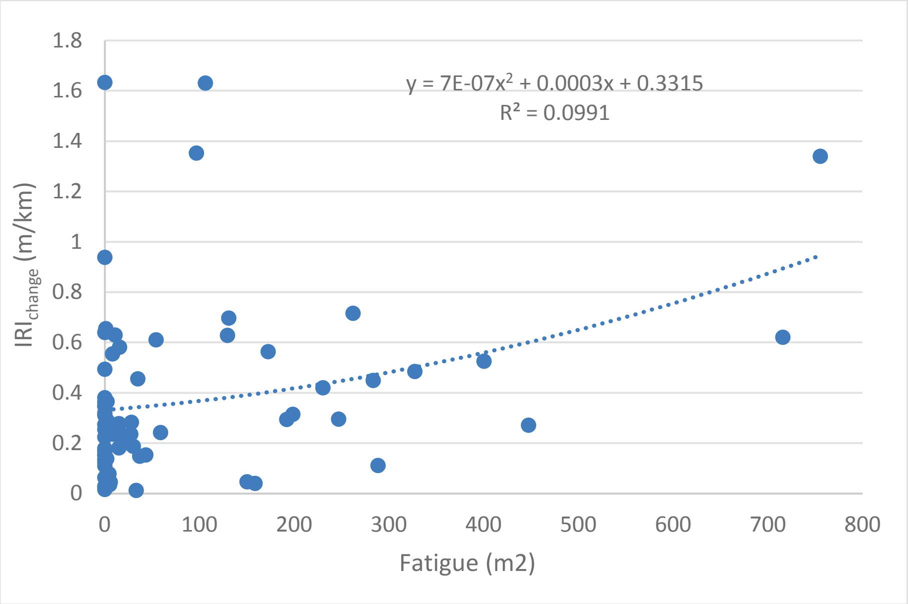

***Fig. 7 – Fatigue vs IRI$_{change}$***

### *4.7 Regression Analysis*

After studying the effect of individual parameters on pavement smoothness, multiple regression analysis was performed to obtain an equation representing the effect of all these parameters on pavement smoothness, characterised by IRI value. Equation 1 was obtained because of this analysis:

$$\mathrm{IRIchange} = -0.2571 + 0.023904 * \mathrm{AGE} + 5.68\mathrm{E}-06 * \mathrm{PRECIPITATION} - 0.01131 * \mathrm{TEMPERATURE} + 0.000138 * \mathrm{AADTT} + 0.000431 * \mathrm{FATIGUE} + 0.061274 * \mathrm{RUTTING} \tag{1}$$

The regression statistics for this equation is shown in Table 1 and Table 2.

**Table 1 - Regression statistics for all parameters**

| Factor | Values |
|---|---|
| **Multiple R** | 0.652612 |
| **R Square** | 0.425903 |
| **Adjusted R Square** | 0.372081 |
| **Standard Error** | 0.272482 |
| **Observations** | 71 |

**Table 2 - Summary output for regression for all parameters**

| | Coefficients | Standard Error | t Stat | P-value |
|---|---|---|---|---|
| **Intercept** | -0.2571 | 0.283786 | -0.90595 | 0.368358 |
| **Age (years)** | 0.023904 | 0.010737 | 2.226322 | 0.02952 |
| **Annual Precipitation (mm)** | 5.68E-06 | 7.51E-05 | 0.075711 | 0.939885 |
| **Temperature (C)** | -0.01131 | 0.012959 | -0.87272 | 0.386077 |
| **AADTT** | 0.000138 | 3.93E-05 | 3.512087 | 0.000821 |
| **Fatigue ($m^2$)** | 0.000431 | 0.000218 | 1.977758 | 0.052265 |
| **Rutting (mm)** | 0.061274 | 0.011666 | 5.252319 | 1.83E-06 |

Equation 1 was used to predict the $IRI_{change}$ values of the sections and a graph of predicted vs calculated IRI values was then plotted as shown in Fig. 8. While performing multiple regression analysis, IRI is kept in Y-axis and the parameters as precipitation, temperature, age, rutting fatigue and AADTT were kept in X-axis and with the assistance of Excel multiple regression, the value of $R^2$ was calculated to be 0.425903.

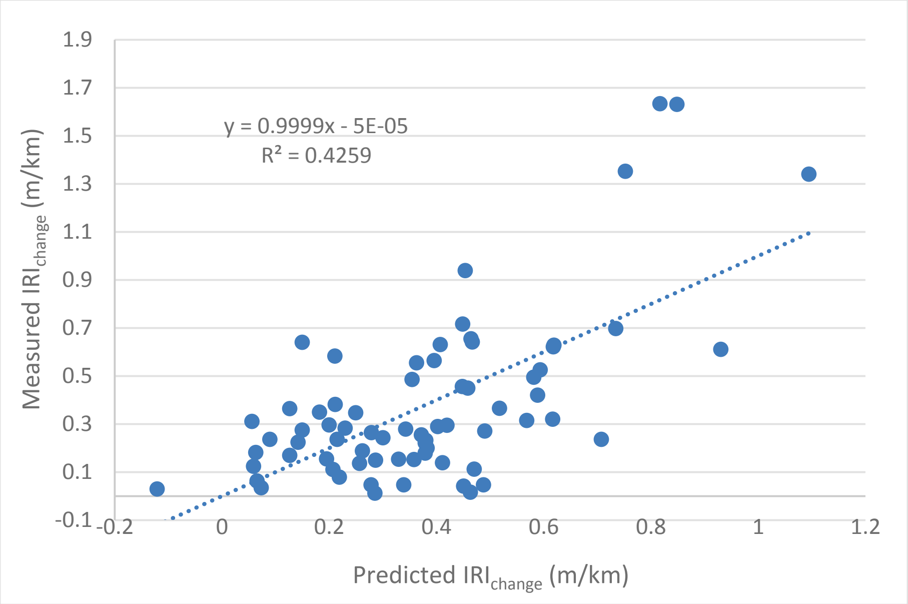

***Fig. 8 – Predicted $IRI_{change}$ vs. Measured $IRI_{change}$ for all parameters***

In order to increase the accuracy of the IRI prediction, the sections were separated into three different groups according to each section annual precipitation.

The three annual precipitation ranges are the following: Less than 200mm; between 200mm and 900mm; and over 900mm. This follows the idea introduced by Perera et al. where different models were developed according to diverse environmental zones, on his research, sections were separated according to the amount of annual precipitation, grouping sections with less than 508mm of precipitation per year were considered in a dry zone, where sections with a precipitation higher than 508mm per year would be considered in a wet zone [19].

With the following modifications three regression analysis were developed and with it three equations to predict the IRI change, as seen on Table 3 and Table 4.

**Table 3 - Regression statistics for different annual precipitation ranges**

| Factor | Precipitation <200mm | Precipitation >200mm and <900mm | Precipitation >900mm |
|---|---|---|---|
| **Multiple R** | 0.80139 | 0.7061 | 0.785459 |
| **R Square** | 0.642227 | 0.498577 | 0.616945 |
| **Adjusted R Square** | 0.540006 | 0.283682 | 0.463723 |
| **Standard Error** | 0.289854 | 0.285148 | 0.149199 |
| **Observations** | 28 | 21 | 22 |

**Table 4 - Summary output for regression for all parameters**

| Factor | Precipitation <200mm | Precipitation >200mm and <900mm | Precipitation >900mm |
|---|---|---|---|
| **Intercept** | -0.18737 | -0.54096 | -0.96604 |
| **Age (years)** | 0.011219 | 0.03807 | 0.081319 |
| **Annual Precipitation (mm)** | -0.00069 | 0.000635 | 0.000283 |
| **Temperature (C)** | 0.005323 | -0.00837 | -0.01862 |
| **AADTT** | -6.8E-05 | 0.000116 | 0.0003 |
| **Fatigue ($m^2$)** | 0.000747 | -8.3E-05 | -0.0001 |
| **Rutting (mm)** | 0.086837 | 0.032886 | 0.032025 |

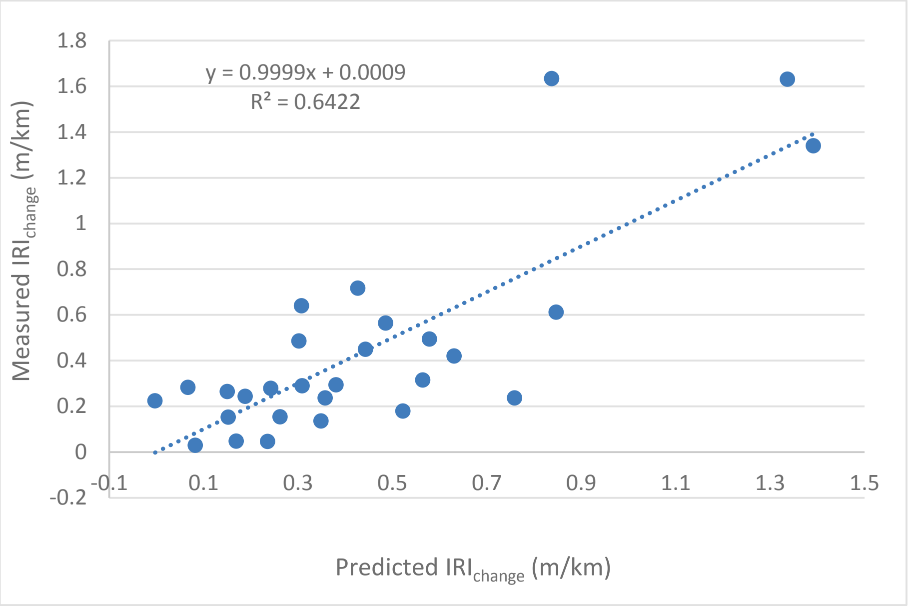

*Fig. 9 – Predicted $IRI_{change}$ vs. Measured $IRI_{change}$ for annual precipitation <200mm*

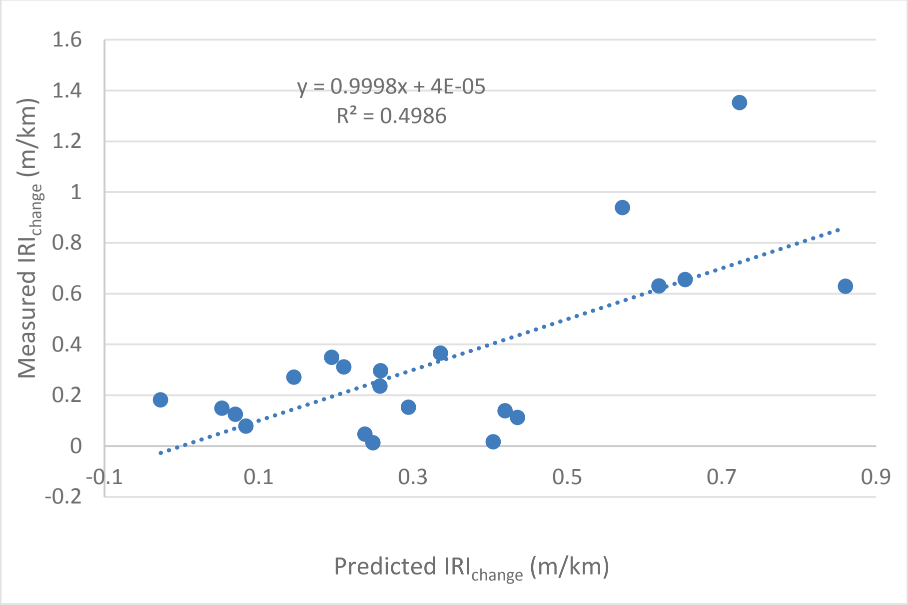

***Fig. 10 – Predicted IRI$_{change}$ vs. Measured IRI$_{change}$ for annual precipitation >200mm and <900mm***

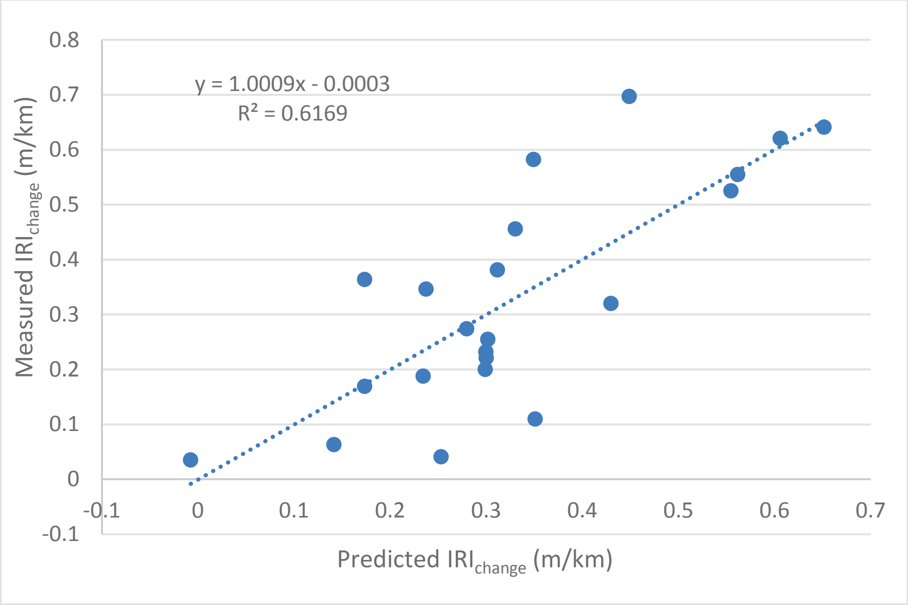

***Fig. 11 – Predicted IRI$_{change}$ vs. Measured IRI$_{change}$ for annual precipitation >900mm***

$$\text{IRIchange} = -0.18737 + 0.011219 * \text{AGE} + 0.00069 * \text{PRECIPITATION} + 0.005323 * \text{TEMPERATURE} - 6.8\text{E} - 05 * \text{AADTT} + 0.000747 * \text{FATIGUE} + 0.086837 * \text{RUTTING} \tag{2}$$

$$\text{IRIchange} = -0.54096 + 0.03807 * \text{AGE} - 0.000635 * \text{PRECIPITATION} - 0.00837 * \text{TEMPERATURE} + 0.000116 * \text{AADTT} - 8.3\text{E} - 05 * \text{FATIGUE} + 0.032886 * \text{RUTTING} \tag{3}$$

$$\text{IRIchange} = -0.96604 + 0.081319 * \text{AGE} + 0.000283 * \text{PRECIPITATION} - 0.01862 * \text{TEMPERATURE} + 0.0003 * \text{AADTT} - 0.0001 * \text{FATIGUE} + 0.032025 * \text{RUTTING} \tag{4}$$

Using Equation 2, as seen on Fig. 9, the obtained $R^2$ was 0.642227, indicating a stronger correlation between the roughness in those sections when compared with Equation 1 $R^2$ that was equal to 0.425903. For sections that had an annual precipitation between 200mm and 900mm, the difference was smaller, with the $R^2$ obtained from Equation 3, and noticed on Fig. 10, was equal to 0.498577. For the last group of sections, with the annual precipitation higher than 900mm, the $R^2$

obtained from Equation 4, and noticed on Fig. 11, was equal to 0.616945. This small increase shows that separating sections among different groups of annual precipitation increases the $IRI_{change}$ prediction.

In order to increase the accuracy even more of the IRI prediction, the sections were still separated into three different groups according to each section annual precipitation. However, on this regression, precipitation was removed from the $IRI_{change}$ analysis, since it was already used to separate sections in the three different groups. The other parameters were then interrelated among themselves and then another multiple regression analysis was performed. This time $IRI_{change}$ was correlated to Age, Temperature, AADTT, Fatigue, Rutting, Age*Temperature, Age*AADTT, Age*Fatigue, Age*Rutting, Temperature*AADTT, Temperature*Fatigue, Temperature*Rutting, AADTT*Fatigue, AADTT*Rutting, and Fatigue*Rutting. The results of the regression analysis can be seen on Table 5 and Table 6.

**Table 5 - Regression Statistics for model**

| Factor | Precipitation <200mm | Precipitation >200mm and <900mm | Precipitation >900mm |
|---|---|---|---|
| **Multiple R** | 0.967256 | 0.927048 | 0.949287 |
| **R Square** | 0.935585 | 0.859418 | 0.901146 |
| **Adjusted R Square** | 0.855066 | 0.437671 | 0.490508 |
| **Standard Error** | 0.1627 | 0.252646 | 0.103785 |
| **Observations** | 28 | 21 | 22 |

**Table 6 - Summary output for model**

| | Precipitation <200mm | Precipitation >200mm and <900mm | Precipitation >900mm |
|---|---|---|---|
| **Intercept** | 9.167426 | 1.342149 | 0.629808 |
| **Age** | -0.26408 | -0.37635 | 0 |
| **Temperature** | -0.47253 | -0.03772 | 0 |
| **AADTT** | -0.00208 | 0.000619 | -0.0028 |
| **Fatigue (m2)** | 0.010818 | 0.000771 | 0.058036 |
| **Rutting (mm)** | -0.98641 | -0.0617 | -0.64127 |
| **Age * Temperature** | 0.025878 | 0.018155 | -0.00592 |
| **Age * AADTT** | -0.00011 | -1.4E-05 | -0.00017 |
| **Age * Fatigue** | -0.00061 | -0.00086 | -0.00383 |
| **Age * Rutting** | -0.00053 | 0.020509 | 0.072739 |
| **Temperature * AADTT** | 0.000108 | -3.2E-05 | 0.000312 |
| **Temperature * Fatigue** | -0.00028 | -0.00037 | -0.00193 |
| **Temperature * Rutting** | 0.037168 | -0.0052 | -0.00045 |
| **AADTT * Fatigue** | -1.1E-06 | 2.66E-06 | -8.2E-06 |
| **AADTT * Rutting** | 0.000138 | 1.18E-05 | 0.000232 |
| **Fatigue * Rutting** | 0.000174 | 0.001538 | 0.00056 |

$$\mathrm{IRIchange} = 9.167426 - 0.26408 \ast X1 - 0.47253 \ast X2 - 0.00208 \ast X3 + 0.010818 \ast X4 - 0.98641 \ast X5 + 0.025878 \ast X1 \ast X2 - 0.00011 \ast X1 \ast X3 - 0.00061 \ast X1 \ast X4 - 0.00053 \ast X1 \ast X5 + 0.000108 \ast X2 \ast X3 - 0.00028 \ast X2 \ast X4 + 0.037168 \ast X2 \ast X5 - 1.1E - 06 \ast X3 \ast X4 + 0.000138 \ast X3 \ast X5 + 0.000174 \ast X4 \ast X5 \tag{5}$$

$$\mathrm{IRIchange} = 1.342149 - 0.37635 \ast X1 - 0.03772 \ast X2 + 0.000619 \ast X3 + 0.000771 \ast X4 - 0.0617 \ast X5 + 0.018155 \ast X1 \ast X2 - 1.4E - 05 \ast X1 \ast X3 - 0.00086 \ast X1 \ast X4 + 0.020509 \ast X1 \ast X5 - -3.2E - 05 \ast X2 \ast X3 - 0.00037 \ast X2 \ast X4 - 0.0052 \ast X2 \ast X5 + 2.66E - 06 \ast X3 \ast X4 + 1.18E - 05 \ast X3 \ast X5 + 0.001538 \ast X4 \ast X5 \tag{6}$$

$$\mathrm{IRIchange} = 0.629808 - 0.0028 \ast X3 - 0.0028 \ast X4 + 0.058036 \ast X5 - 0.00592 \ast X1 \ast X2 - 0.00017 \ast X1 \ast X3 - 0.00383 \ast X1 \ast X4 + 0.072739 \ast X1 \ast X5 + 0.000312 \ast X2 \ast X3 - 0.00193 \ast X2 \ast X4 - 0.00045 \ast X2 \ast X5 - 8.2E - 06 \ast X3 \ast X4 + 0.000232 \ast X3 \ast X5 + 0.00056 \ast X4 \ast X5 \tag{7}$$

Where, $X_1$ = Age; $X_2$ = Temperature; $X_3$ = AADT; $X_4$ = Fatigue; $X_5$ = Rutting.

Equation 5, Equation 6, and Equation 7 were used to predict the IRI values of the sections and a graph of predicted vs calculated IRI values was then plotted as shown in Fig. 12, Fig.13, and Fig.14.

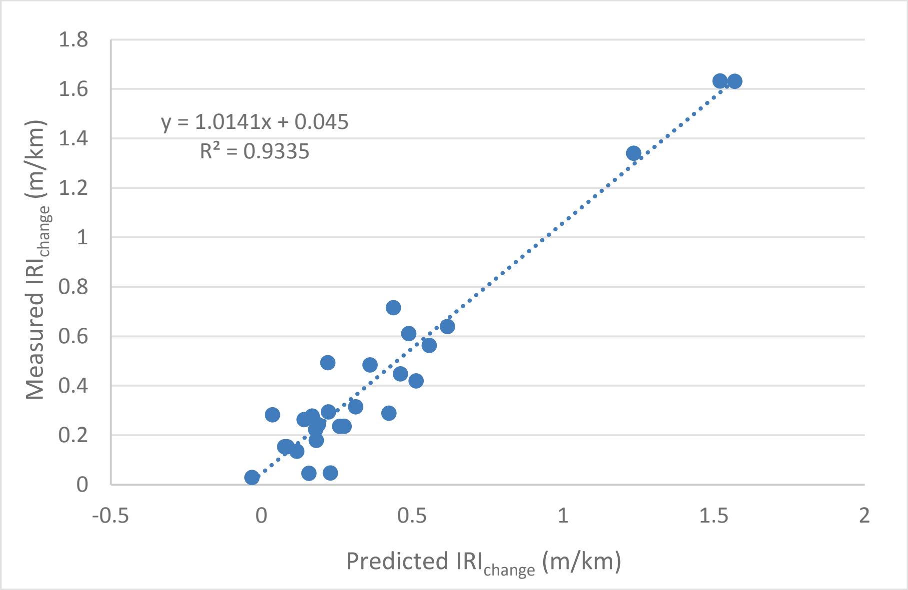

*Fig. 12 – Predicted IRI vs. Measured IRI for annual precipitation <200mm model*

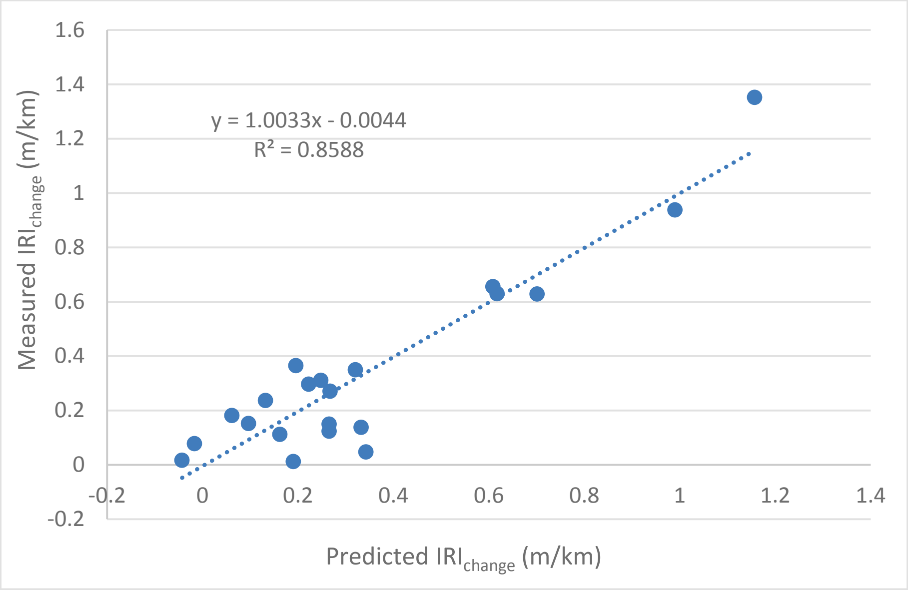

*Fig. 13 – Predicted IRI vs. Measured IRI for annual precipitation >200mm and <900mm model*

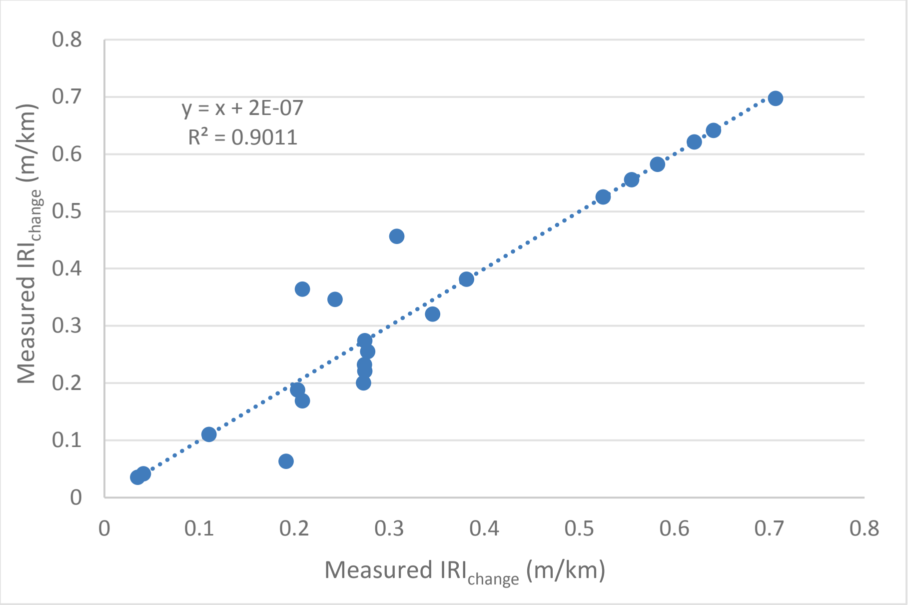

***Fig. 14 – Predicted IRI vs. Measured IRI for annual precipitation >900mm model***

This gave a better result than the previous model, whereas the R squares in this model were increased to 0.935585, 0.859418, and 0.901146 respectively. The improvement in the R square is due to interrelationship of the parameters. As Age could determine the fatigue of a pavement, AADTT could affect the Rutting in the pavement. The factors are related within themselves. Then the new models were formed and used to predict the new $IRI_{change}$. The trend line shows linear relationship for the three cases. This indicated that the regression model obtained predicts the IRI value of a section with at least 85.9% of accuracy.

## 5 Conclusions and Results

An analysis was performed using LTPP data available, with 63 pavement sections being selected, for a total of 71 observations for the State of California. This research used IRI as the pavement smoothness measurement, and took under consideration, the time sequence nature of the collected data available for the sections. Analysis of pavement roughness indicated that the combination of annual precipitation, age, temperature, AADTT, fatigue, and rutting have significant effect on pavement smoothness. However, when the parameters are analyzed separately, no correlation was found between different parameters and the pavement roughness. Results indicate that separating the sections into distinct groups according to the annual precipitation increases the analysis accuracy from 42.59% to 64.22% for sections with the annual precipitation being less than 200mm. From 42.59% to 49.85% to for sections with an annual precipitation between 200mm and 900mm, and finally, from 42.59% to 61.69% for sections with annual precipitation higher than 900mm. When developing an interrelation among the different parameters, results indicated that the analysis accuracy increased significantly when compared to initial analysis or when compared with results obtained with the separation according to the annual precipitation. Equations developed can be used for predicting $IRI_{change}$ for sections with annual precipitation less than 200mm with 93.5% accuracy, for sections with annual precipitation between 200mm and 900mm with 85.9% accuracy, and lastly, for sections with annual precipitation greater than 900mm with 90.1% accuracy. The effort of this research is to refine and contribute to a higher understanding of the different effects that the studied factors have on the pavement smoothness.

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