Evaluation of the Pavement Road Roughness: A Case of San Juan, La Union

Orlean G. **DELA CRUZ** [a], Christian A. **MENDOZA** [b], Kristel D. **LOPEZ** [c], Charlotte A. **MAHINAY** [d], Eric Andrei G. **MARCELINO** [e]

[a,b,c,d,e] *Civil Engineering Department of Polytechnic University of the Philippines*
[b] *Graduate School of Polytechnic University of the Philippines*

[a] *Email:* ogdelacruz@pup.edu.ph
[b] *Email:* *mendozachristian244@gmail.com*
[c] *Email:* *kristellopez3098@gmail.com*
[d,e] *Same as the first author; Email:* ogdelacruz@pup.edu.ph

Abstract: International Roughness Index (IRI) is the universal standard for measuring pavement roughness. The capacity of pavement to meet the road users' demands over its planned service period reflects its level of efficiency. Therefore, research related to the review of road paving outcomes must evaluate the pavement conditions and initial confirmation findings using jolt values calculated from the experiment. The paper uses regression modeling to define the subjective connection of driving efficiency at various speeds through IRI. Besides, using the speedometer, a mobile android application that could predict with fair certainty. The researchs' setting was on parts of roadways extracted by the local PMS. The study considered the speed range of 40 to 80 kph with an interval of 10 kph within a 2,200-meter road portion. Future research may include pavement and age specifications as another variable that considers the road users' characteristics that may affect their sensitivity to ride quality.

Keywords: International Roughness Index (IRI); Pavement Management System (PMS); Jolt; road pavement; pavement performance

1. INTRODUCTION

One of the crucial difficulties of highway engineers, way back in the 1920s, was the vehicle vibration resulting from the road pavement unevenness. (R. Haas & Hudson, 1978) defined this unevenness as the distortion of ride quality. In 1982, the International Road Roughness Experiment (IRRE) was organized, with the support of the World Bank, and conduct a research experiment in Brazil to abet evaluate a variety of equipment and find a suitable standard of roughness measurement (Jihanny et al., 2018). (Sidess et al., 2020), the outcome of all assessments and efforts led to the establishment of IRI in 1986. Thenceforth, the International Roughness Index (IRI) is the universal standard for measuring pavement roughness. It has become the most widely employed pavement index today (Sidess et al., 2020).

The fleet growth of heavy traffic every year, especially the rise in standard axle load, causes road deterioration. Therefore, rough pavements have an eminent influence on public approval, safety, and the economy. In the report (Achmadi et al., 2017), ride quality is one of the travelers' most significant conditions to review roadway pavements. Furthermore, road users generally prefer the flatness or comfort on the road, so it is necessary to check the state periodically (Surbakti & Doan, 2018). According to (Zoccali et al., 2017), monitoring the road pavement condition and its service life will assure a proper and maintained road network. With this, (PMS) is necessary, which serves as a tool that assists the road agencies in road maintenance strategies and evaluation, appropriate intervention threshold identification, and providing pavement in a serviceable condition over time (Sidess et al., 2020; Zoccali et al., 2017).

Many PMS incorporate both visual and automatic surveys in their plan and utilizing several indices for the evaluation (Zoccali et al., 2017). (Papageorgiou, 2019) The commonly used performance indicators include the Riding Comfort Index (RCI), Pavement Condition Index (PCI), IRI, etc. The IRI standard has generally been used worldwide for evaluating road systems (Achmadi et al., 2017). Even the Federal Highway Performance Monitoring System (FHPMS) has used IRI as the prime indicator for road profiles evaluation (Papageorgiou, 2019). And so, road roughness is essential for the pavement condition assessment (G Loprencipe et al., 2014; Sayer & Karamihas, 1995), and an important aspect to be included in any Pavement Management System (PMS) (Bonin et al., 2017; Han & Kobayashi, 2013; Giuseppe Loprencipe et al., 2017; Shahin, 2005). Its main advantage is that it is a time-stable index, which generates the same values even when applied to the same road, as stated by (Sayer & Karamihas, 1995).

In the Philippines, the following are the standard for road roughness: road segments with an average IRI of 1-3, <3-5, <5-7, and <7 are in "good," "fair," "poor," and "bad" condition, respectively as stated in Department Order (D.O.) No. 234 Series of 2004. Nevertheless, the roughness index does not include the range of a vehicle's velocity and the specific pavement type. A year ago, a program initiated by the Department of Public Works and Highways (DPWH) that identify and gauge the roughness of national roads based on IRI started. Results may show a significant input to the Pavement Management System (PMS). However, D.O. No. 137 Series of 2016 stated that most primary roads funded under the General Appropriations Act (GAA) and even foreign assisted projects did not meet the required IRI value set by DPWH. With that, the government imposes a non-payment of road projects that do not comply with the IRI provision (de la Cruz et al., 2019). For this reason, the department has no option but to implement non-payment for road projects with non-conformity to the IRI requirements.

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The pavement's capacity to meet the road user's demands over its planned service period reflects its efficiency level. Therefore, research related to the review of road paving outcomes must evaluate the pavement conditions. This study focuses on providing superficial road roughness and IRI information on a local road in San Juan, La Union that may support and enhance the introduction of PMS in municipalities.

2. METHODOLOGY

2.1 Study Area

San Juan, a second-class municipality in the La Union province, is considered the Northern Philippines' surfing capital. It's one of the ultimate getaways for surfing fans and the safest spot to chill and feel positive vibes. However, due to congestion, the vehicles' axial load, the harsh weather conditions, and low-quality materials create defects in the pavement composition. Moreover, the roads' roughness is an essential aspect of the roadway, which defines the road's condition and influences the vehicle's running costs, travel time, and safety. Therefore, the researchers selected the McArthur Highway, given the large amount of average daily travel it received in the past years for having world-class tourist spot destinations of the North.

2.2 Experiment Design

It was using "speedometer," a mobile application that records time being during the quick stop of the SUV. A Toyota HiAce was selected as the testing vehicle for the data collection analysis to produce a broader range of results to reach up to 100 km/h. However, a study suggested an updated IRI model that used a drive speed of 50 kph for the quarter-car model on the ground that the urban driving speed is significantly lower than the 80 km/h used in the original IRI (la Torre et al., 2002). Besides, it served for the researchers' safety and abiding on the speed limit of the city. Therefore, the researchers considered a range speed of 40 to 80 kph with an interval of 10 kph running within a 2,200 meters road segment along McArthur Highway in San Juan, La Union. Figure 2 shows the condition of the road.

2.3 International Roughness Index (IRI)

The IRI is the flatness of the road surface shown by the number of vertical variations in the road surface for each unit road length (mm/km) (Lukman et al., 2020). It is an empirical determinant of road pavement efficiency that critically defines the road's elongated profile as its flatness (Maria et al., 2020). Besides, IRI is the universal benchmark for calculating pavement roughness and has been the most commonly used pavement index (Sidess et al., 2020). In addition, Federal Highway Administration (FHWA) has developed and released appropriate IRI values for highways (Yu et al., 1974). However, such IRI requirements do not apply to local streets. Furthermore, an investigation also emerged that a rise in IRI and vehicle speed could lead to a deterioration in riding comfort (Zhang et al., 2018).

B. Goenaga et al. (2017) explained that the pavement roughness is the primary variable that produces the vertical excitation in vehicles. Pavement profiles are the main determinant of (i) discomfort perception on users and (ii) dynamic loads generated at the tire-pavement interface; hence its evaluation constitutes an essential step on a Pavement Management System.

The pavement roughness is the primary variable that produces the vertical excitation in vehicles, as explained by B. Goenaga et al. (2017). In addition, there are primary determinants in considering the pavement profiles condition (i) discomfort perception on users and (ii) dynamic loads generated at the tire-pavement interface. Henceforward, the evaluation still constitutes steps in the Pavement Management System.

In evaluating pavement conditions, many methods are emerging on how to come up with a redefining result. Yet, the researchers are looking into gaps in assessing the pavement conditions with different approaches. Since finding the holes, discovering everyday challenges, collecting and examining specific data on pavement conditions will help design proper road maintenance to keep it in the long run (Jurkevičius et al., 2020).

2.4 Regression Modeling

Jerk or jolt is the time rate change of acceleration, significant for mechanics and acoustics applications (Schot, 1978). Besides, a jolt is linearly proportional to the IRI at any given speed and roughly linearly proportional to the IRI's moving speed (Yu et al., 1974).

The properties of jolt have been taken advantage of as one of the test variables in this study. The versatility and non-complexity of this made it easier to come up with promising results. However, to become reliable, the researchers have added statistical tools to supplement the resulting regression model. The strong relationship among the variables made an uncanny result, as shown in the next section.

af-aot=J

afdt= (ao+Jt) dt

Δv = aot + jt22

j = 2 (vf - vot2 - aot) **(1)**

The study used regression modeling to investigate the relationship between the speed of a vehicle and the road's roughness. While there are many regression models, different models serve as trials to determine the suitable prediction model. To conclude, the linear and polynomial regression up to the fourth (4) degree with the highest determination (R2) coefficient and exceeding 0.90 is the agreed, suitable prediction model.

Thus, the regression equation is well-defined in Equation 2, where *J* is the jolt in m/s^3, *V* is the velocity in kph, and *IRI* in m/km. Equation 2 calculates the IRI threshold by back-computation with the given estimated jolt value in Equation 1 and the different velocities during the experiment.

$$j = 1.041x10^{-5}V^4 + 1.92x10^{-5}V^3IRI - 2.475x10^{-2}V^2IRI^2 - 1.442VIRI^3 - 41.922IRI^4 - 3.0136x10^{-3}V^3 - 1.693x10^{-1}V^2IRI - 17.703VIRI^2 + 456.562IRI^3 + 5.996x10^{-1}V^2 + 70.08VIRI - 1656IRI^2 - 104.673V + 2045.02IRI + 109.071 \quad (2)$$

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3. RESULTS AND DISCUSSION

The researchers used regression modeling to create an appropriate regression equation to determine the value of jolt using IRI values. As shown in table 1, the result formed the IRI criterion for the ride quality with varying speeds. Table 1 comprises the result of the experiment and the taken regression analysis. The proposed IRI criteria for the speed kph are 80, 70, 60, 50, 40.

- For “Good” ratings are ≤ 0.4472, ≤ 0.4473, ≤ 0.448, ≤ 0.567, and ≤ 0.569, respectively.
- For “Fair” ratings are 0.4473 – 0.500, 0.4474 – 0.531, 0.449 – 0.555, 0.568 – 0.8706, and 0.601 – 0.962 respectively.

- For “Poor” ratings are 0.5114 – 0.543, 0.532 – 0.606, 0.556 – 0.612, .8712 – 0.976, and 1.065 – 1.252, respectively.
- And, for “Bad” ratings are ≥ 0.5900, ≥ 0.658, ≥ 0.701, ≥ 1.263, and ≥ 2.362, respectively.

Table 2 shows the computed variation amplitude of the road sections to confirm and predict the jolt at a certain speed. Based on the result, on varying speed, the jolt values at each IRI level roughly follow a normal distribution as shown in the table, which comprises the sample size mean, standard deviation, and the ratio of the standard deviation to mean.

Figure 1 shows the graph of the actual jolt in the x-axis that is computed using equation 1 and given actual speed-related IRI. While in the y – axis is the predicted jolt calculated using equation 2 and listed in Table 2.

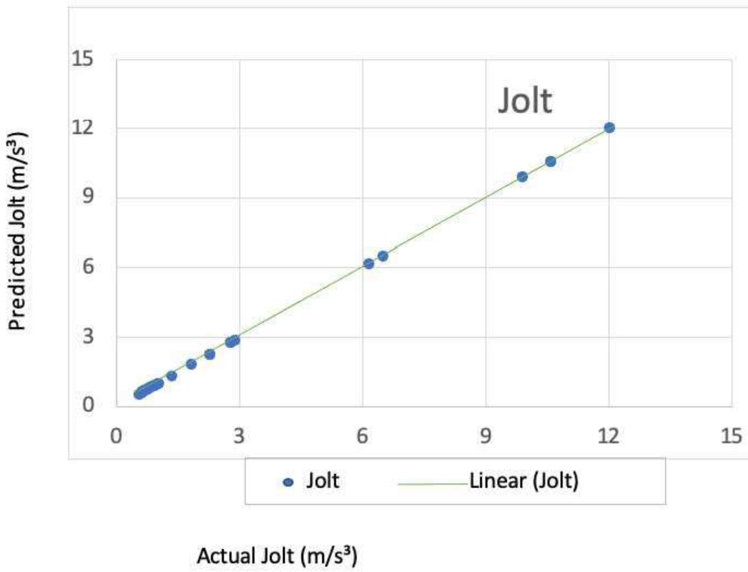

Figure 1. Relationship of Actual and Predicted Jolt

Profiles with the same IRI value can vary in jolt at the same speed because of the variations in the characteristics of the profile. The explanation for this variance is to be investigated and further estimated.

Table 1. Suggested IRI threshold at Varying Speeds

Ride Quality	Jolt (m/s^3)	IRI Various Speeds Threshold (units: m/km)				
		80 km/h	70 km/h	60 km/h	50 km/h	40 km/h
Good	≤ 0.90	≤ 0.4472	≤ 0.4473	≤ 0.448	≤ 0.567	≤ 0.569
Fair	1.00	0.4473 – 0.500	0.4474 – 0.531	0.449 – 0.555	0.568 – 0.8706	0.601 – 0.962

Poor	1.50	0.5114 – 0.543	0.532 – 0.606	0.556 – 0.612	0.8712 – 0.976	1.065 – 1.252
Bad	> 2.00	≥ 0.5900	≥ 0.658	≥ 0.701	≥ 1.263	≥ 2.362

Table 1 contains the suggested IRI threshold at Varying Speeds. Values as concurred on the experiment done in San Juan, La Union. The ranges are: 0.90m/s^3, 1.00 to 1.40m/s^3, 1.5m/s^3 ≤ 2m/s^3, and greater than 2m/s^3 for good, fair, bad and poor respectively.

Table 2. Average Jolt at Varying IRI

Statistics	$J_{average\ (m/s^3)}$			
	IRI = 2.919	IRI = 3.362	IRI = 3.502	IRI = 3.273
Sample Size *n*	6	6	6	6
Mean, μ	0.47572	0.756	0.6035	2
Standard Deviation, ***δ***	0.07	0.086	0.04	0.216
Relative Error, ***δ*/μ**	14.71%	11.38%	6.63%	10.8%

Table 2 incorporates the statistical analysis done on the average IRI values from the Department of Public Works and Highways - Bureau of Quality and Safety (DPWH-BQS). Since the frequency error relativity for the four (4) IRI values is low, it has validated the formulated regression modeling and rectified the standard thresholds on varying speed and road conditions.

4. CONCLUSIONS

Road maintenance administration is advantageous for tracking and reviewing the road network's current status, determining network needs, and preparing road maintenance (Jurkevičius et al., 2020). Researchers to consider the variety of speed limits IRI requirements for local streets. To develop the speed-dependent IRI thresholds, jolt, known as the primary cause of rough ride, is used (Yu et al., 1974).

Based on the findings, the following conclusions are as follows:

1. Descriptive speed-ride quality of selected urban roads in San Juan, LA Union are 0.90m/s^3, 1.00 to 1.40m/s^3, 1.5m/s^3 ≤ 2m/s^3, and greater than 2m/s^3 for good, fair, bad and poor respectively. The Jolt at the IRI threshold and the Jolt at a speed-related IRI threshold are slightly different because of the regression results.
2. The velocity of 50kph falls to the "Bad" rating, the velocities 40kph and 60kph mark a "Fair" rating, and 70kph and 80kph observe a "Good" rating.

3. The IRI thresholds for the speed 40kph to 80kph were established and then yields the suggested IRI criteria. Hence, benchmarks show that the value of jolt is directly proportional to the value of IRI.

This study will not only give light to the effect of road roughness. Still, it will also create an avenue for continuing many studies about the road roughness index and the other factors incorporated with it. For example, future research may include pavement and age specifications as another variable that considers the road users' characteristics that may affect their sensitivity to ride quality.

The researchers shall add the varying degrees of pavements as a recommendation for future study. This study only focuses on determining Ride Quality by assessing the road pavement condition considering IRI and Jolt as variables.

5. ACKNOWLEDGMENT

We offer our kindest gratitude to our support system – our Engineering Science Department Family, John Pual J. Pauya, Jobelle S. Dajac, and Juland A. Padilla, who never failed to support us. To Megawide Foundation, for giving us the means to perform our study, we may not be able to fulfill our experimentation without you. We also offer our kindest gratitude to our support system (our family), who never failed to support us emotionally and financially.

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