EVALUATION OF PAVEMENT IRREGULARITIES USING A MOBILE APPLICATION

Martin Paucara Rojas[1], Víctor Yapuchura Platero[2], Joao Giancarlo Condorchoa Clares[3], Rodrigo Alexander Vicente Mercado[4], Nahuel Humberto Molero Yáñez[5]

1 Universidad Nacional Jorge Basadre Grohmann,https://orcid.org/0000-0002-5169-102X
mpaucarar@unjbg.edu.pe
2 Universidad Nacional Jorge Basadre Grohmann, https://orcid.org/0000-0002-2209-9852
vyapuchurap@unjbg.edu.pe
3 Universidad Nacional Jorge Basadre Grohmann,https://orcid.org/0009-0005-3441-437X
jcondorchoac@unjbg.edu.pe
4 Universidad Nacional Jorge Basadre Grohmann, https://orcid.org/0009-0009-2628-3962
ravicentem@unjbg.edu.pe
5 Universidad Nacional Jorge Basadre Grohmann,https://orcid.org/0000-0002-4272-4360
nmoleroy@unjbg.edu.pe

Abstract: The research evaluated the surface conditions of the TA-642 road in Tacna, Peru, using the TotalPave application on smartphones to measure the roughness and passability of the pavement. Descriptive-exploratory analysis methods with a quantitative approach were employed, collecting data every 400 meters over a distance of 12.8 km at speeds of 80 km/h, utilizing the sensors and GPS of the mobile device. The results showed an International Roughness Index (IRI) of 3.78 m/km and a passability score of 2.58, both classified as "Regular" according to Peruvian standards. These values indicate that the road has surface irregularities that may cause discomfort and damage to vehicles during transit. The study confirms the potential of TotalPave to effectively assess pavement roughness in a versatile, economical, and reliable manner compared to traditional methods. This mobile application uses smartphone sensors to measure the vehicle's vertical acceleration and accurately estimate the IRI.In conclusion, the use of mobile applications enables the assessment of road conditions and the planning of timely maintenance interventions, optimizing resources and improving transportation quality. This is particularly relevant in countries with budget constraints for road construction and maintenance.

Keywords: TotalPave, Roughness, Irregularity, Passability and Smartphone.

Introduction

Maintaining road infrastructure in good condition is essential to ensure the safety and efficiency of land transport. In this sense, pavement assessment plays a crucial role in identifying and managing deterioration issues that impact both road users and maintenance entities. One of the increasingly important areas of research in this area is to understand how road surface conditions affect economically, as they can not only cause discomfort during traffic, but also cause damage to vehicles and increase maintenance costs for road authorities. Despite the growing interest in this topic, the precise relationship between pavement conditions and their economic implications has yet to be fully explored.

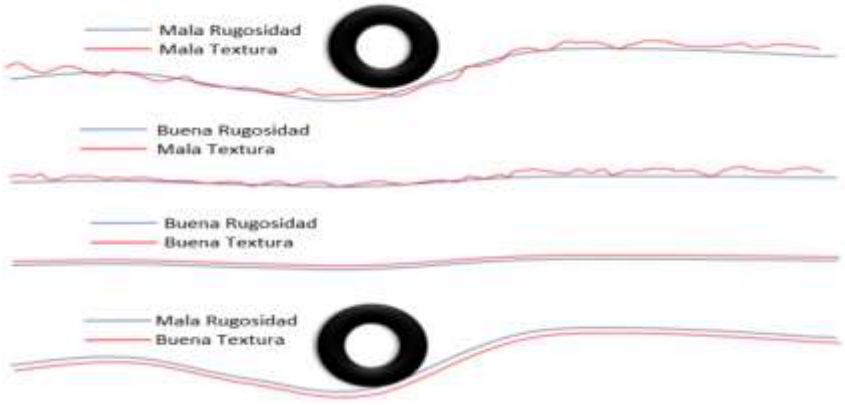
Roughness is the result of surface irregularities on a road and is an important factor that negatively affects the quality of travel, affecting costs due to travel delays, higher fuel consumption, tire wear and increased costs of maintenance and rehabilitation of the road. (Thilak, R., Anjaneyappa, J., Mehta, V., Pharle, C., Rajapur, C. y Borah, S., 2021)

For , there are various methodologies to measure roughness, considering state-of-the-art equipment, which are expensive and scarce, thanks to technological advancement they have

evolved varying in accuracy and speed in obtaining the IRI values applied for smartphones with reliable accuracy results. (Porras, H., Ramón, J., Mejía, Y. y Parra, J., 2014)

Figure 1

Relationship of texture and irregularity in a pavement. In original language English



Note. Irregularity present on the surface of the pavement, taken from (Forslof, 2014)

Figure 1 shows the correlation between roughness and texture, as explained by (Forslof, 2014), if the IRI increases, the texture worsens, on poor texture gravel roads, adequate roughness, followed by the case where roughness and texture are good, finally, the case of high roughness in a good texture.

For which, ; considers roughness as an important parameter that reflects on the comfort and safety for the user who uses the road and considers the use of a smartphone to obtain roughness data through easy-to-monitor applications at a low cost. On the other hand, he assures that the Smartphone uses sensors, accelerometers and GPS of the same, where its results are of reliable accuracy.(Vargas, N. y Cárdenas, L., 2018)(Aydin, MM., Yildirim, MS. y Forslof, L., 2018)(Yeneh, S., Mahmoudzadeh, A., Azizpour, M. y Golroo, A., 2019)

Smartphones are used to detect surface roughness from a moving vehicle where it sends to a central server to process IRI values. Also, there are different approaches to measure the roughness of the surface in a pavement from the most expensive, which require a lot of time and specialized operators, so, our research according to what is indicated because, for projects limited by the budget for the construction and maintenance of roads, low-cost methodologies are developed with optimal results, the use of applications for Smartphones.(Kumar, R., Mukherjee, y Singh, V.P., 2017)(Al-Mansour, A. y Al-Qaili, A., 2022)

As he claims, smartphones use their 3D accelerometers to obtain data from the vertical acceleration of a vehicle to accurately predict reliable IRI values and, as such, researchers have developed methodologies to obtain IRI data from a road quickly and accurately at an economical cost.(Aleadelat, W., Ksaibati, K., Wright, C. y Saha, P., 2018)(Aboah, A. y Adu-Gyamfi, Y., 2020)

Within the framework of the research, it considers that the quality of a road affects comfort, road safety and traffic conditions, at the same time it influences the increase in emission levels produced by the vehicle, so the measurement of surface irregularities is obtained through the TotalPave application for smartphones. (Oliveira, V., Rocha, M. y Castelo, T., 2020)

Where, , is a Canadian company located in New Brunswick which aims to develop applications for use in pavement engineering and the optimization of resources at a very low cost, the information obtained is sent to the central server in the TotalPave cloud, where the data is processed to determine the IRI. (TotalPave Inc, 2022)

According to what is indicated by , currently the advantages in the use of the application is the immediate obtaining of the IRI with good accurate yields and lower costs compared to traditional methods. (Cavalcante de Almeida, L., Lacerda de Oliveira, F. y Passos, S., 2018)

The ASTM Standard (E1926-08, 2021), describes the method for obtaining IRI values in pavements using longitudinal profiles. Where , considers IRI a measure of a vehicle's reaction to the road profile and irregularity expressed in meters per kilometer. (Tamrakar, P., Wayne, M. y Broadhead, K., 2019)

The roughness in IRI terms, in the Tacna region, will have a maximum value of 2.5 m/km for roads on new pavements and 2.8 m/km as a maximum value in resurfaced pavements in accordance with the CE.010 standard (MTC, 2013)(MVCyS, 2010)

Table 1

Pavement quality as a function of roughness

Category	Range by road type IRI (m/km)		Ride quality
	Interstate	Non-interstate	Interstate and non-interstate
Very good	< 0.95	< 0.95	Acceptable
Well	0,95 – 1,48	1,42 – 1,48	0 -2,68
Regular	1,50 – 1,90	1,50 – 2,68	
Poor	1,89 – 2,68	2,70 – 3,50	Not acceptable
Very poor	> 2.68	> 3.50	> 2.68

Note. Taken from the U.S. Department of Transportation

Table 1 shows pavement quality based on IRI, according to the U.S. Department of Transportation, classified into five categories by . Where roads with less than 0.95 m/km are considered to be of very good quality providing a smooth and comfortable ride, as the IRI increases the quality of the pavement decreases making journeys less comfortable and an IRI above 2.68 and 3.50 m/km is considered unacceptable for the ride quality.(Islam, S., Buttlar, W., Aldunate, R. y Vavril, W., 2014)

Table 2

Pavement quality in Peruvian regulations

Surface Layer Status	Paved Roughness	Unpaved Roughness
Well	0 < IRI < 2.8	IRI < 6.0
Regular	2.8 < IRI < 4.0	6.0 < IRI < 8.0
Bad boy	4.0 < IRI < 5.0	8.0 < IRI < 10.0
Very bad	IRI > 5.0	IRI > 10.0

Note. Taken from NTP CE 010 Urban Pavements

Table 2 shows the surface condition of the pavement according to Peruvian regulations where the IRI value ranges for paved roads are stricter compared to unpaved roads, reflecting an expectation of higher travel quality on paved surfaces.

Peruvian standards are more flexible with respect to allowable roughness compared to U.S. standards, especially for unpaved roads, reflecting rougher conditions, which are influenced by local factors such as climate, topography, road construction and maintenance practices.

Table 3 presents a classification of serviceability where PSI is a measure that assesses the quality of a road's surface from the user's point of view, on a scale of 0 to 5, where 0 represents

an impassable surface and 5 a perfect surface. The table shows that, depending on the range of PSI values, it is possible to determine the rating of the serviceability and the type of intervention necessary to improve or maintain the quality of the road, where this information is very useful for the planning and management of road maintenance and rehabilitation projects.

Table 3

Rating of serviceability and type of intervention according to the PSI value

PSI	Qualification	Type of Intervention
0 - 1	VERY BAD	Reconstruction
1 - 2	SUITCASE	Reconstruction
2 - 3	REGULAR	Rehabilitation
3 - 4	GOOD	Rehabilitation
4 - 5	VERY GOOD	Maintenance

Note. Adapted guide table (AASHTO, 1997)

In this article, we develop the use of the methodology of the TotalPave application on smartphones to determine the irregularity index and qualify the serviceability in the pavement of the TA-642 highway, La Yarada -Los Palos district, Tacna region.

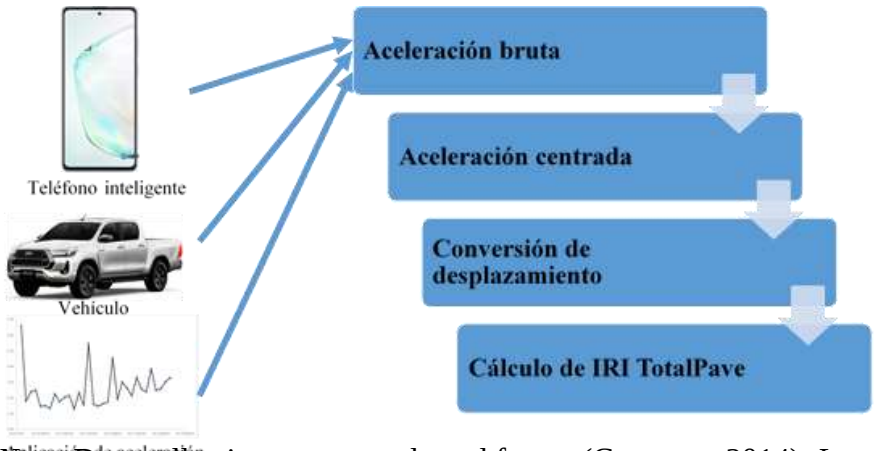
Materials and methods

This research is classified as basic, with a descriptive-exploratory approach, as indicated by Hernández and Mendoza (2018). Its main objective is to generate knowledge about the evaluation of pavement irregularities through the TotalPave application. The study was carried out on the TA-642 highway, located in the La Yarada - Los Palos district, which extends over 12,800 meters and connects with the Tacna region.

For data collection, the TotalPave application was used, which allows measuring the roughness of the pavement efficiently. Figure 2 illustrates the data collection process, which includes device configuration, field data collection, and information processing. This process has been adapted from Cameron (2014), suggesting that it is based on a method previously validated in the literature.

Figure 2

Data collection using TotalPave



Note. Data collection process, adapted from . (Cameron, 2014) .*In original language Spanish*

The interface of the TotalPave app, presented in Figure 3, is critical for users to interact with the app on their smartphones. The operation and calibration of the application have been

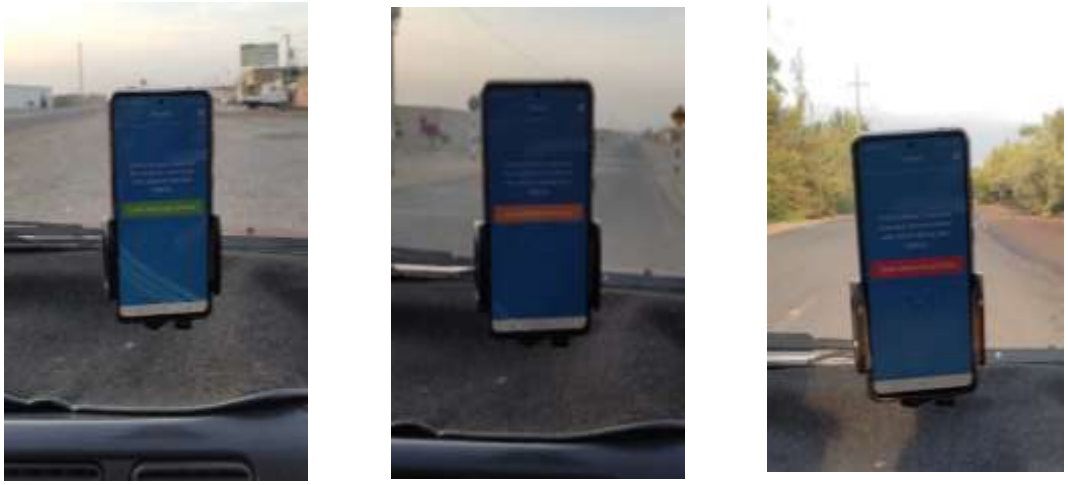
documented by TotalPave Inc. (2022), guaranteeing its reliability and functionality. The interface is designed to be intuitive and easy to use, which is essential for effective data collection.

Figure 3
TotalPave application interface

Note. Operability and calibration of the TotalPave application for smartphones, taken from . (TotalPave Inc, 2022). *In original language Spanish*

The methodology for obtaining data is detailed in Figure 4, which shows a Samsung Galaxy Note 10 smartphone placed in the center of the windshield of a 2023 Toyota Raize car. Proper fixation of the device is crucial to ensure that it remains level during data collection.

Figure 4
Data Collection Home Screen



Note: The figure visualizes data collection using the TotalPave application.

The IRI values obtained are stored on the TotalPave website, where data collection begins at the beginning of the evaluated section, maintaining a uniform speed between 60 km/h and 70 km/h to ensure maximum accuracy. At the end of the assessment, the data is uploaded to the TotalPave account via an internet connection. To obtain the IRI values determined by the application, you must enter the TotalPave web portal to download the determined values using a username and password granted by the company, marpaucarar@virtual.upt.pe

Road serviceability is determined by calculating the Present Serviceability Index (PSI), which is obtained by analyzing the results of the average IRI of each lane and the weighted IRI of the evaluated roadway. To rate serviceability, the formula developed by William Paterson, an expert in road engineering, is used:

$$PSI = 5.85 - 1.68(IRI^{0.5}) \quad (1)$$

This approach allows for an accurate assessment of pavement condition and provides valuable information for planning maintenance interventions

Results and discussion

Results

The evaluation of the International Roughness Index (IRI) on the Tacna-Los Palos highway (TA-642) using the TotalPave application has provided valuable information on the current state of the running surface. Analysis of the data collected in the left and right lanes reveals patterns and trends that are critical to understanding road conditions and planning appropriate maintenance interventions.

The results obtained from the recording of IRI values every 400 meters in both lanes are presented. The data show significant variations in the behavior of the IRI, with notable differences between the left and right lanes. These differences highlight the need for detailed analysis to identify the underlying causes and develop specific strategies for each section of the road.

Table 4 shows the IRI values obtained in the left lane of the road, with an average of 3.65 m/km. The values vary throughout the evaluation, highlighting a notable increase in the section from Km 4+000.00 to Km 4+400.00, where a value of 7.66 m/km is recorded, where maintenance measures are required in the identified critical section, possibly due to factors such as traffic, weather conditions or lack of maintenance.

Table 4
IRI value registration obtained with the TotalPave application in the left lane

EVALUATION DATE	EVALUATION AREA	PROGRESSIVE START	FINAL PROGRESSIVE	SURFACE TYPE	STARTING LATITUDE	FINAL LATITUDE	LEFT LANE
26/03/2024	TACNA-LOS PALOS HIGHWAY TA - 642	Km 0+0.00	Km 0+400.00	ASPHALTING	-18.1504	-18.1521	4.89
		Km 0+400.00	Km 0+800.00		-18.1545	-18.1553	3.08
		Km 0+800.00	Km 1+200.00		-18.1577	-18.1586	3.28
		Km 1+200.00	Km 1+600.00		-18.161	-18.1618	3.56
		Km 1+600.00	Km 2+000.00		-18.1643	-18.1651	3.45
		Km 2+000.00	Km 2+400.00		-18.1675	-18.1683	3.34
		Km 2+400.00	Km 2+800.00		-18.1708	-18.1716	3.38
		Km 2+800.00	Km 3+200.00		-18.174	-18.1748	3.64
		Km 3+200.00	Km 3+600.00		-18.1773	-18.1781	3.46
		Km 3+600.00	Km 4+000.00		-18.1805	-18.1814	3.85
		Km 4+000.00	Km 4+400.00		-18.1838	-18.1846	7.66
		Km 4+400.00	Km 4+800.00		-18.1871	-18.1879	3.69
		Km 4+800.00	Km 5+200.00		-18.1903	-18.1911	3.49
		Km 5+200.00	Km 5+600.00		-18.1936	-18.1944	3.23
		Km 5+600.00	Km 6+000.00		-18.1968	-18.1976	3.52

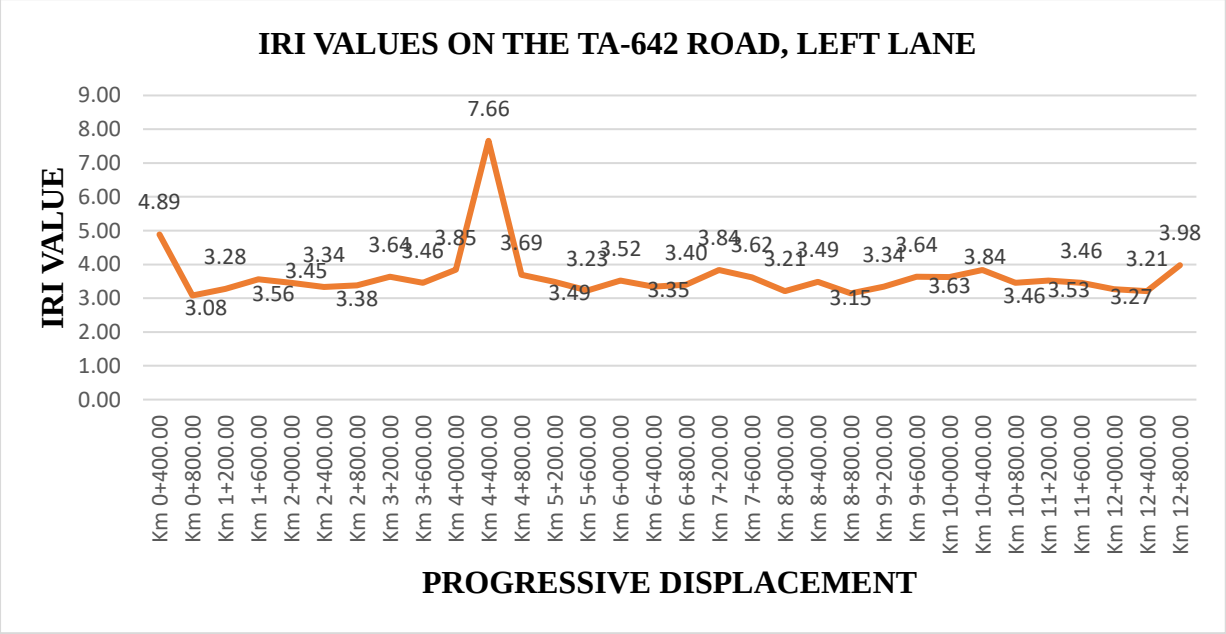
Km 6+000.00	Km 6+400.00	-18.2001	-18.2009	3.35
Km 6+400.00	Km 6+800.00	-18.2034	-18.2042	3.40
Km 6+800.00	Km 7+200.00	-18.2067	-18.2076	3.84
Km 7+200.00	Km 7+600.00	-18.2101	-18.2109	3.62
Km 7+600.00	Km 8+000.00	-18.2134	-18.2142	3.21
Km 8+000.00	Km 8+400.00	-18.2167	-18.2176	3.49
Km 8+400.00	Km 8+800.00	-18.2201	-18.2209	3.15
Km 8+800.00	Km 9+200.00	-18.2234	-18.2243	3.34
Km 9+200.00	Km 9+600.00	-18.2268	-18.2276	3.64
Km 9+600.00	Km 10+000.00	-18.2301	-18.2309	3.63
Km 10+000.00	Km 10+400.00	-18.2334	-18.2343	3.84
Km 10+400.00	Km 10+800.00	-18.2368	-18.2376	3.46
Km 10+800.00	Km 11+200.00	-18.2401	-18.2409	3.53
Km 11+200.00	Km 11+600.00	-18.2434	-18.2442	3.46
Km 11+600.00	Km 12+000.00	-18.2467	-18.2475	3.27
Km 12+000.00	Km 12+400.00	-18.25	-18.2508	3.21
Km 12+400.00	Km 12+800.00	-18.2532	-18.2541	3.98

Note. The table shows the IRI value obtained every 400 m, using the TotalPave application in the left lane with an average equal to 3.65 m/km

Figure 5 graphically illustrates the variation of the IRI in the left lane, showing a fluctuating behavior, where the IRI values coincide with the sections where the highest values were recorded in the table, which reaffirms the need for attention in those specific areas.

Figure 5

IRI value behavior every 400 m; Left Lane



Note. The figure shows the route by IRI value determined in the left lane

In Table 5, the IRI values of the right lane show an average of 3.91 m/km, although the values are generally higher than in the left lane, the range of variation is less pronounced. The maximum value in this lane is 6.26 m/km, also in the first section, which indicates that in both lanes they present roughness problems, the right lane has a more homogeneous behavior

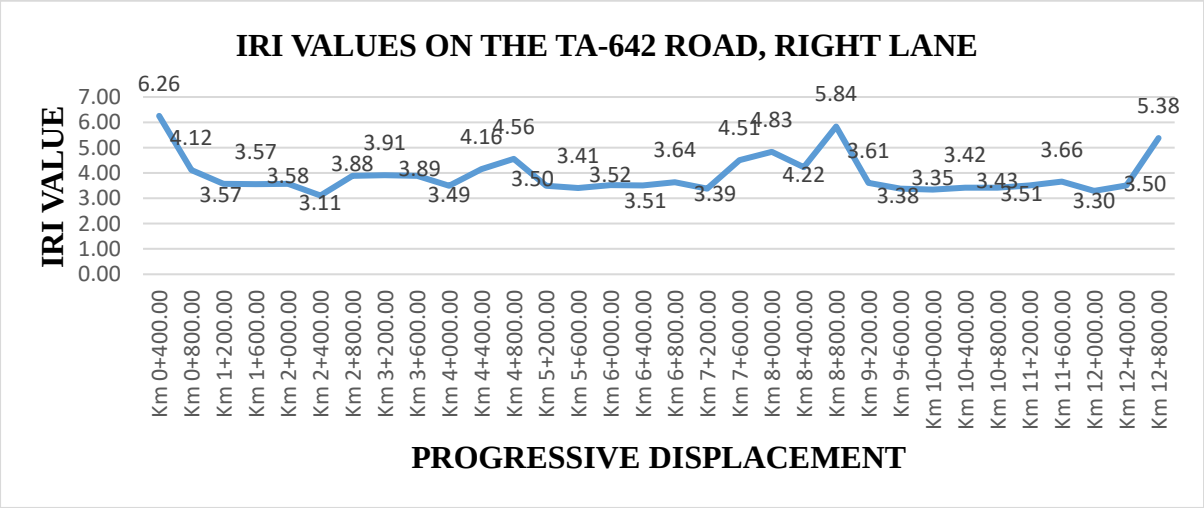
Table 5
IRI **Value** *Registration Obtained with TotalPave App in Right Lane*

EVALUATION DATE	EVALUATION AREA	PROGRESSIVE START	FINAL PROGRESSIVE	SURFACE TYPE	STARTING LATITUDE	FINAL LATITUDE	RIGHT LANE
26/03/2024	TACNA-LOS PALOS HIGHWAY TA - 642	Km 0+0.00	Km 0+400.00	ASPHALTING	-18.2556	-18.256	6.26
		Km 0+400.00	Km 0+800.00		-18.2524	-18.2532	4.12
		Km 0+800.00	Km 1+200.00		-18.2491	-18.25	3.57
		Km 1+200.00	Km 1+600.00		-18.2459	-18.2467	3.57
		Km 1+600.00	Km 2+000.00		-18.2426	-18.2434	3.58
		Km 2+000.00	Km 2+400.00		-18.2393	-18.2401	3.11
		Km 2+400.00	Km 2+800.00		-18.2359	-18.2368	3.88
		Km 2+800.00	Km 3+200.00		-18.2326	-18.2334	3.91
		Km 3+200.00	Km 3+600.00		-18.2293	-18.2301	3.89
		Km 3+600.00	Km 4+000.00		-18.2259	-18.2268	3.49
		Km 4+000.00	Km 4+400.00		-18.2226	-18.2234	4.16
		Km 4+400.00	Km 4+800.00		-18.2192	-18.2201	4.56
		Km 4+800.00	Km 5+200.00		-18.2159	-18.2167	3.50
		Km 5+200.00	Km 5+600.00		-18.2126	-18.2134	3.41
		Km 5+600.00	Km 6+000.00		-18.2092	-18.2101	3.52
		Km 6+000.00	Km 6+400.00		-18.2059	-18.2067	3.51
		Km 6+400.00	Km 6+800.00		-18.2025	-18.2034	3.64
		Km 6+800.00	Km 7+200.00		-18.1993	-18.2001	3.39
		Km 7+200.00	Km 7+600.00		-18.196	-18.1968	4.51
		Km 7+600.00	Km 8+000.00		-18.1928	-18.1936	4.83
		Km 8+000.00	Km 8+400.00		-18.1895	-18.1903	4.22
		Km 8+400.00	Km 8+800.00		-18.1863	-18.1871	5.84
		Km 8+800.00	Km 9+200.00		-18.183	-18.1838	3.61
		Km 9+200.00	Km 9+600.00		-18.1797	-18.1805	3.38
		Km 9+600.00	Km 10+000.00		-18.1765	-18.1773	3.35
		Km 10+000.00	Km 10+400.00		-18.1732	-18.174	3.42
		Km 10+400.00	Km 10+800.00		-18.17	-18.1708	3.43
		Km 10+800.00	Km 11+200.00		-18.1667	-18.1675	3.51
		Km 11+200.00	Km 11+600.00		-18.1634	-18.1643	3.66
		Km 11+600.00	Km 12+000.00		-18.1602	-18.161	3.30
		Km 12+000.00	Km 12+400.00		-18.1569	-18.1577	3.50
		Km 12+400.00	Km 12+800.00		-18.1537	-18.1545	5.38

Note. The table shows the IRI value obtained every 400 m, using the TotalPave application in the right lane IRI AVERAGE equal to 3.91 m/km

Similarly, Figure 6 represents the behavior of the IRI in the right lane, where the visualization allows us to observe that the values are more consistent, there are sections that require intervention, especially those that exceed the threshold of 4.0 m/km, which is considered a critical limit for surface quality.

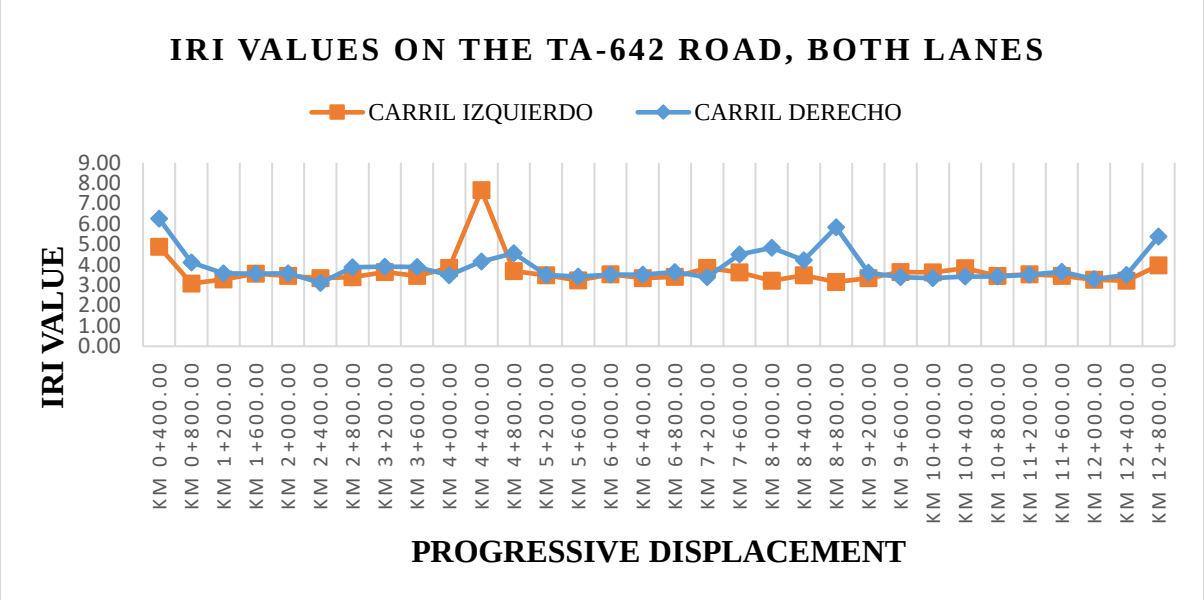
Figure 6
IRI value behavior every 400 m; right lane



Note. The figure shows the route by IRI value determined in the right lane

Figure 7 provides a comparison between the IRI values of both lanes. It is noted that although the left rail has a lower average, it features higher peaks than the right, suggesting that despite its better average, it has sections with significantly worse rolling conditions.

Figure 7
IRI value behavior every 400 m, in both lanes



Note. In the figure we can see the comparison of the IRI value obtained every 400 m, in both evaluation lanes.

Finally, Figure 8 shows the evaluation path on both lanes using the TotalPave application, with a color code indicating the quality of the IRI. This visual representation makes it easy to identify critical stretches that need immediate attention.

Figure 8

Right and left lane assessment tour using the TotalPave app

Note. In the figure we can see the route along the TA-624 road by color according to the IRI value.

Table 6 presents the values of the International Roughness Index (IRI) and the Serviceability Index (PSI) obtained on the Tacna-Los Palos highway (TA-642) during the evaluation carried

out on March 26, 2024. The data reflect an IRI range ranging from 3.65 m/km to 3.91 m/km for the right lane, with an average of 3.78 m/km, and a PSI ranging from 2.64 to 2.53, with an average of 2.58. These results indicate that both lanes are in regular service conditions, suggesting a pavement quality that could affect the comfort and safety of users.

The average IRI of 3.78 m/km is considered acceptable, but it is close to the upper limit of the "fair" category, implying that the road has certain irregularities that could negatively impact the road user experience. The regular service rating, reflected in the PSI values, indicates that users could begin to perceive discomfort while driving, especially in sections where the IRI is close to 4.0 m/km. This result highlights the need for continuous monitoring and proactive maintenance to prevent further deterioration that could lead to more critical service conditions.

In addition, when comparing IRI and PSI values, a direct correlation is observed between surface roughness and perception of service. As the IRI increases, the PSI tends to decrease, which is consistent with the existing literature that states that a higher IRI is associated with a lower quality of service. This emphasizes the importance of keeping IRI values within acceptable limits to ensure a safe and comfortable driving experience. Consequently, it is suggested that corrective actions be implemented in the sections identified with higher IRI values to improve the quality of the pavement and, therefore, user satisfaction.

Table 6

Registration of **IRI values** *and PSI value for its final qualification of the Tacna – Los Palos TA-642 highway*

				INTERNATIONAL ROUGHNESS INDEX		SERVICEABILITY	
EVALUATION DATE	EVALUATION AREA	PROGRESSIVE START	FINAL PROGRESSIVE	IRI RIGHT RAIL	IRI RIGHT RAIL	PSI RIGHT LANE	PSI RIGHT LANE
26/03/2024	TACNA-LOS PALOS HIGHWAY	Km 0+0.00	Km 12+800.00	3.65	3.91	2.64	2.53
			AVERAGE	**3,78**	m/km	**2,58**	
	PAVEMENT RATING AND SERVICEABILITY			REGULAR		REGULAR	

Note. The table shows the IRI values of the right and left lane and based on this, the serviceability was determined for the qualification of the condition of the pavement and the serviceability as REGULAR.

Discussion

The discussion of the results obtained in the evaluation of the International Roughness Index (IRI) and the Serviceability Index (PSI) on the Tacna-Los Palos highway (TA-642) provides a comprehensive view of the state of the road infrastructure and its impact on the safety and comfort of users.

Table 4 and Table 5 show the IRI values obtained in the left and right lanes, respectively, where the results indicate that the left lane has an average IRI of 3.65 m/km, while the right lane has an average of 3.91 m/km. Although both lanes maintain a range considered acceptable, the values are indicative that the road has irregularities that may affect passability. This difference in averages suggests that the left rail performs better in terms of roughness, which is relevant for maintenance planning.

Figure 6 illustrates the behavior of the IRI in the right lane, showing a lower variability compared to the left lane. However, the IRI value of 6.26 m/km at the start of the route indicates that there are critical sections that need to be addressed. This finding is consistent with the literature suggesting that variations in the IRI may be associated with factors such as traffic type and weather conditions, highlighting the importance of further analysis to understand the causes of impairment.

Figure 7 provides a visual comparison between the IRI values of both lanes. It is observed that, although the left lane has a lower average, it presents higher values in certain sections, which suggests that, despite its better overall performance, there are sections that require urgent attention. This is crucial, as variations in roughness can influence road safety, increasing the risk of accidents and affecting the comfort of users.

Figure 8 shows the road assessment course using the TotalPave app, highlighting sections with different IRI levels via colour coding. Areas in red indicate a high IRI, allowing for quick identification of sections that require intervention, this visual representation is valuable for road managers as it makes it easier to prioritise corrective actions based on the severity of the deterioration.

The analysis of the PSI values in Table 6 complements the IRI assessment, providing insights into the perception of road service. PSI values, which range from 2.64 to 2.53, indicate that users may experience discomfort while driving. The observed correlation between the IRI and the PSI reinforces the idea that an increase in surface roughness translates into a decrease in service quality, which can negatively impact user satisfaction.

The "fair" rating for both indices suggests that although the road is passable, it is not in optimal condition, raising the need to implement a regular maintenance program that addresses irregularities in the pavement surface. Failure to address these issues could lead to more severe deterioration and an increase in long-term maintenance costs.

In addition, it is important to consider the factors that contribute to road deterioration, heavy traffic, adverse weather conditions, and the quality of the materials used in construction are elements that should be evaluated in order to develop more effective maintenance strategies. A detailed analysis of these factors will allow road authorities to make informed decisions about the interventions needed.

The implementation of a continuous monitoring system of the IRI and PSI is recommended to detect changes in road quality in a timely manner. Not only will this allow interventions to be prioritised, but it will also help to establish a history of data that can be useful for future assessments and maintenance planning.

Conclusions

The evaluation of the International Roughness Index (IRI) on the Tacna-Los Palos highway (TA-642) has allowed a detailed view of the quality of the road infrastructure, where the results obtained show that the average IRI in the left lane is 3.65 m/km, while in the right lane it is 3.91 m/km. Although both lanes are in an acceptable range, the variability in the IRI values indicates that there are critical sections that require immediate attention, especially in the left lane, where an IRI value of 7.66 m/km was recorded.

The correlation between IRI values and the Serviceability Index (PSI) reinforces the direct relationship between surface roughness and users' perception of service. PSI values, which range from 2.64 to 2.53, suggest that users could experience discomfort while driving, which can affect road safety. This relationship highlights the importance of keeping IRI values within acceptable limits to ensure a safe and comfortable driving experience.

The analyses carried out with the TotalPave application have made it possible to identify specific sections that require intervention where the visual representation of the data in the figures provides an effective tool for the prioritization of corrective actions. The areas in red in the figure corresponding to the evaluation path indicate sections with a high IRI, which facilitates the identification of critical sections that need to be addressed urgently.

Research has also revealed that the left lane, despite having a lower average IRI, has high roughness values that exceed acceptable limits. This indicates that despite their improved overall left-wing performance, there are sections that require a more rigorous maintenance approach. On the other hand, the right lane, considered more uniform, also has sections that exceed the critical threshold of 4.0 m/km, indicating that it is not free of drawbacks.

The need for a regular maintenance program is evident. Because, ignoring irregularities in the running surface could result in more serious deterioration, increasing long-term maintenance costs and putting the safety of users at risk. Therefore, it is advisable to establish a maintenance plan that addresses the identified critical sections and that includes constant monitoring of the quality of the road.

In conclusion, the findings of this research provide valuable information that can guide maintenance decisions and improve the quality of road infrastructure, thus ensuring a safer and more comfortable driving experience for users of the Tacna-Los Palos highway.

References

AASHTO. (1997). *AASHTO Guide to the Design of Pavement Structures 1993.* Lima - Peru: Institute for the Development of Pavements in Peru.

Aboah, A. & Adu-Gyamfi, Y. (2020). Smartphone-Based pavement roughness estimation using deep learning with entity embedding. *Advances in Data Science and Adaptive Analysis, 12*(3). doi:10.1142/S2424922X20500072

Aleadelat, W., Ksaibati, K., Wright, C., & Saha, P. (2018). Evaluation of pavement roughness using an Android-based Smartphone. *Journal of Transportation Engineering: Pavements, 144*(3). doi:10.1061/JPEODX.0000058

Al-Mansour, A. & Al-Qaili, A. (2022). An Application of android sensors and Google Earth in pavement maintenance management systems for developing countries. *Applied Sciences, 11*(12), 5636. doi:10.3390/application12115636

Aydin, MM., Yildirim, MS., & Forslof, L. (2018). The use of smartphones to estimate road roughness: a case study in Turkey. *Engineering Sciences (NWSAENS), 13*(3), 247-257. doi:10.12739/NWSA.2018.13.3.1A0416.

Cameron, C. (2014). *Innovative means of collecting international roughness index using smartphone technology.* Canada: University of New Brunswick.

Cavalcante de Almeida, L., Lacerda de Oliveira, F., & Passos, S. (2018). Estudo da condicão de surfície em rodovias por meio do uso de aplicativo para Smartphone. *Transportes, 25*(2), 70-83. doi:10.14295/transportes.v25i2.1406

E1926-08. (2021). *Standard practice for roads and parking lots pavement condition index surveys.* ASTM International. doi:standard-astm-e1926-08-2021-108303

Forslof, L. (2014, November 30). *https://www.linkedin.com/pulse/20141130211746-97325448-roughness-and-texture/*. Retrieved from

https://www.linkedin.com/pulse/20141130211746-97325448-roughness-and-texture/: https://www.linkedin.com

Islam, S., Buttlar, W., Aldunate, R., & Vavril, W. (2014). Measurement of pavement roughness using an Android-Based Smartphone application. *Transportation Research Record*, 30-38. doi: https://www.researchgate.net/publication/283296999

Kumar, R., Mukherjee, & Singh, V.P. (2017). Community sensor network for monitoring road roughness using smartphone. *Journal of Computing in Civil Engineering, 3*(31). doi:10.1061/(ASCE)CP.1943-5487.0000624

MTC. (2013). *Road Manual - EG-2013.* Ministry of Transport and Communications. doi:R.D. N° 22-2013-MTC/14

MVCyS. (2010). *Technical Standard CE.010 Urban Pavements.* Lima-Peru: Ministry of Housing, Construction and Sanitation. doi:https://cdn-web.construccion.org/normas/files/tecnicas/Pavimentos_Urbanos.pdf

Oliveira, V., Rocha, M., & Castelo, T. (2020). Evaluation of the influence of the surface condition of urban floors on the generation of vehicular emissions. *34th ANPET Congress of Research and Education in Transport.* Brazil: Associação Nacional de Pesquisa e Ensino em Transportes. Retrieved from https://repositorio.ufc.br/handle/riufc/56440

Porras, H., Ramón, J., Mejía, Y., & Parra, J. (2014). Automated systems for data acquisition oriented to examine flexible pavements. *Ciencia e Ingeniería Neogranadina, 24*(21), 79-84. doi: ISSN 0124-8170

Tamrakar, P., Wayne, M., & Broadhead, K. (2019). Use of an innovative technology for measuring surface roughness of pavements. *Geo St. John's 2019.* USA: Under Land & Sea. Retrieved from researchgate.net/publication/336345459

Thilak, R., Anjaneyappa, J., Mehta, V., Pharle, C., Rajapur, C., & Borah, S. (2021). Evaluation of pavement roughness using smartphones. *2021 IEEE International Conference on Information Systems and Information Technology for Sustainable Solutions (CSITSS),* 1-7. doi:10.1109/CSITSS54238.2021.9682804.

TotalPave Inc. (September 18, 2022). *Asset Management use TotalPave*. Retrieved from Asset Management use TotalPave: https://totalpave.com/

Vargas, N., & Cárdenas, L. (2018). *Roughness detection system in flexible pavements, with Bluetooth communication and Wi-Fi support from Android device.* Universidad Dsitrital Francisco José de Caldas. doi:hdl.handle.net/11349/8391

Yeneh, S., Mahmoudzadeh, A., Azizpour, M., & Golroo, A. (2019). Validation of smartphone based pavement roughness measures. *ArXiv, 1*, 1-9. doi:10.48550/arXiv.1902.10699