Assessment of Road Rehabilitation Thresholds in Urban Areas Using the International Roughness Index: A Case Study in Metro Manila

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***Abstract*— Urban traffic systems are significant in fostering economic activity and physical mobility. Due to their pavement roughness, these road networks are categorized for ride quality. The study will identify the crucial international roughness index value to set specific rehabilitation thresholds. The resulting findings will highlight the value of data-driven approaches in managing urban infrastructure and offer legislators essential information. The study aims to enhance pavement process management by effectively integrating IRI into existing management systems. A total of 25 road sections were analyzed, and based on a series of analyses, it is recommended to set the rehabilitation threshold for Metro Manila at 4.50 m/km.**

Keywords*— *international roughness index, pavement management systems, threshold index, road rehabilitation

I. INTRODUCTION

A. Background of study

Express highways and main roads serve as the backbones of urban traffic, guaranteeing the connectivity of diverse districts inside the city of Metro Manila, Philippines. The features of urban roadways that have the most significant direct impact on driving quality, safety, and pedestrian experience.

Under moderate maintenance, they must meet the requirements for road user satisfaction regarding service quality and possess the attributes of stability, comfort, and safety. For this point, having a limited budget while maintaining road quality has become a crucial concern for every authorities. Quantity, quality, and form are frequent indicators of the benefits and drawbacks of road service performance. Maintaining fully functional roads and high-quality services is a crucial aspect of contemporary cities and a necessary component of sustainable urban growth.

Typically, a pavement profile is used to determine its roughness or smoothness. According to a 2002 federal highway administration survey [9], roughness is considered the most significant measure of user satisfaction. Thus, measuring road's roughness is a crucial indicator of its state.

The international road roughness index (IRI) is a benchmark for road roughness developed by the World Bank. Since pavement roughness primarily affects pavement service capacity, pavement performance indicators like the present serviceability rating (PSR) or present serviceability index (PSI) are also employed to represent pavement roughness [19]. The following are the standards for road roughness set by the world bank: road segments with an average iri of 1 to 3 are classified as good, > 3-5 as fair, > 5-7 as poor, and > 7 as bad [2].

According to the Department of Public Works and Highways' Road and Bridge Inventory Application , 91% of the routes in concrete and asphalt have been used to pave the nation, and as road infrastructure grows, management of these resources may prove to be a challenge in the future [17]. Following this stance, road damage in Metro Manila has increased due to heavy traffic, erroneous backfilling, and abrupt road reblocking. This has increased the load of maintenance work and caused numerous inconveniences for people. From this vantage point, the assigned road department's top priorities are to execute high-quality maintenance projects and sustain strong road service delivery. This study aims to establish the city's road roughness and evaluate the threshold values to determine whether the current standards should be adjusted.

B. Statement of the problem

It is significant to examine the road repair thresholds in metro manila's urban landscape through the lens of IRI. An examination of the relationship between road conditions, rehabilitation efforts, and their effects on socio-economic dynamics and mobility is done to address the following:

- Determine the current threshold values for the rehabilitation of the roads in metro manila.
- Evaluate the threshold values of acceptance for road roughness characteristics to clarify whether there is room to adjust the current regulations.
- Propose guidelines and recommendations for a suitable index threshold value for the rehabilitation of the roads.
- Examine how the study informs policy-making and urban infrastructure planning to ensure sustainable road rehabilitation practices.

Received: 20-11-2024
Revised: 28-12-2024
Published: 31-12-2024

C. Objective of the research

The study aims to answer the goal of enhancement of decision-making processes related to management of pavement by integrating international roughness index into existing management systems. Specific objectives are as follows:

- To conduct a comprehensive assessment of the current pavement conditions using the IRI as a primary indicator.
- To determine the accepted value of the road roughness index for proper system management.
- To provide standards and suggestions for using the pavement roughness index in the management system of the pavements.

D. Significance of the study

The study aids in optimizing rehabilitation efforts in an environment with limited resources by directing stakeholders to allocate resources proactively toward locations with the highest needs. In addition, data-driven insights are a valuable tool for shaping urban planning choices that aim to ameliorate urban infrastructure's sustainability and resilience. This journal will advance the understanding of transportation engineering and infrastructure management by providing suggestions that can be used in the city and other urban environments across the globe, enhancing the urban experience of the people.

Global standards like the IRI for road maintenance offer a valuable starting point for evaluating the state of roads. However, these standards must sometimes address unique provisions such as metro manila's urban road network. These global thresholds frequently overlook regional stress variables that can hasten urban road deterioration and cause rehabilitation efforts to be implemented too soon or slowly. As a result, imposing a consistent threshold without considering these particular circumstances could lead to less-than-ideal maintenance choices, squandering money on unnecessary repairs, or delaying addressing traffic safety issues. As a result, the study intends to evaluate the given standard, iri, to suit the road network of metro manila through the analysis of road roughness data throughout the years. This would result in more effective and efficient maintenance planning, thus ensuring better road quality for the area's distinctive facade by determining whether the current thresholds need to be adjusted to more closely reflect the local situation.

E. Scope and limitations of the study

The international roughness index (IRI) is the main metric used in this study to determine the road repair thresholds for pavement conditions in metropolitan areas. The geographical scope is limited to two major thoroughfares in metro manila: Roxas Boulevard and Aurora Boulevard. An inertial profiler is the primary data collection tool to obtain accurate iri measurements.

The study is subjected to several limitations. Its geographic focus is limited to only two roads in metro manila, which would limit the findings' applicability to other areas with various traffic patterns and road conditions. The study only uses IRI to measure road roughness, ignoring other pavement properties such as structural integrity and skid resistance. In addition, there are other sections in the area of study that isn't represented by any value due to the state of traffic in the area for the road not to be measured.

II. Review of Related Literature

A. Related Readings

The metropolitan area has a total road length of roughly 3,000 km. From 1980 to 1989, traffic, excluding pedestrian traffic, increased at an annual rate of about 4.5%. The Department of Public Works and Highways (DPWH) mentioned numerous times that breaking and damage had been verified on the main thoroughfares. Road conditions will determine the implementation sequence, which will be carried out to maximize and preserve the overall serviceability of road systems [12].

The International Roughness Index (IRI), created by the World Bank in the 1980s, is currently used to measure road roughness. According to DPWH DO No. 47 Series of 2015, newly built concrete and asphalt road projects will be partially accepted based on the following IRI values [7]. It has been discussed that the national primary road's asphalt and concrete pavement should be valued at 3.00 m/km at most.

Encouraging sustainable and safe modes of transportation is essential for both environmental and public health. The World Health Organization (WHO) can help create safer settings for bicycles, pedestrians, and drivers by concentrating on road rehabilitation and maintenance. This would lower the frequency of road traffic injuries and fatalities. In addition to improving traffic safety, smooth, well-maintained roads stimulate non- motorized transportation options like cycling and walking, increasing physical activity and lowering carbon emissions. The World Health Organization's aim, answering SDG 9 and 12 [23], to promote safe and sustainable transportation systems in metropolitan areas that simultaneously improve the environment and public health is aligned with prioritizing road repair projects that enable active transportation.

Making sure that infrastructure systems are designed and maintained to resist economic and environmental constraints, such as increasing traffic loads, the effects of climate change, and urban growth, is essential to attaining SDG 9. The study adds to the development of better, more durable roads in cities like Metro Manila by utilizing the International Roughness Index (IRI) to evaluate road conditions and determine the ideal repair thresholds. In addition, the study helps by shedding light on the best times to start road rehabilitation in order to stop deterioration that can result in hazardous driving conditions, higher operating costs for vehicles, and higher emissions of greenhouse gases. By utilizing IRI data to establish accurate thresholds, engineers and policymakers may develop maintenance and rehabilitation plans that are sustainable and affordable, prolonging the lifespan of roads and lowering the frequency of expensive repairs. This, in turn, boosts the resilience and durability of transportation infrastructure, minimizing the frequency of costly repairs and disruptions.

In order to create an awareness for responsible consumption and production patterns, SDG 12 is matched with this study, which offers a methodical approach to road maintenance that reduces resource waste and environmental effects. Allocating funds to the most crucial road portions encourages financial responsibility and helps to prevent the financial losses that come with poorly maintained highways or pointless restoration projects.

B. *Related Literature*

World Bank-sponsored research from the 1980s suggested the IRI value. The quarter-car system simulates the road profile, computed using the car's dynamic response. As seen in Figure 1 [3], there are two components to the quarter car simulation model: an unsprung mass and a sprung mass. The latter denotes the half axle/suspension and the set of wheels/tires, while the former indicates the vehicle body. The suspension, represented by a damper and a spring, connects the sprung mass to the unsprung mass.

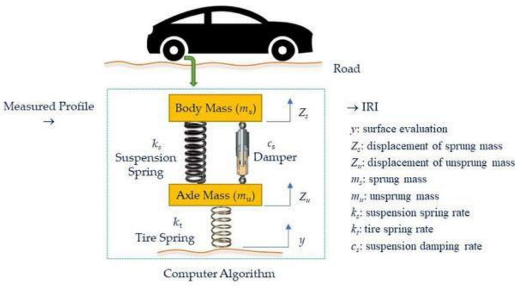

Fig. 1. Illustration of the Algorithm Used to Compute the International Roughness Index.

The IRI mathematically summarizes the longitudinal data. The surface profile of the road in a wheel track simulates the vibrations that a bumpy road would cause in a typical passenger car. It is determined using a conventional quarter-car simulation with a traveling speed of 80 km/h and the reference average rectified slope (RAllS90), which depicts the ratio of the accumulated suspension motion to the distance traveled. It is calculated using surface elevation data from a mechanical profilometer or a topographical survey [15].

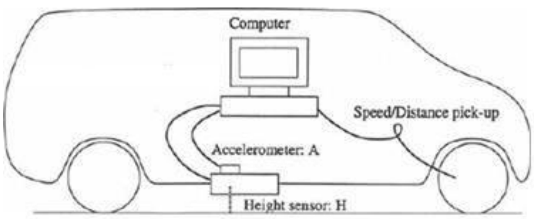

Fig. 2. Schematic Diagram of Interial Profiler.

DPWH has used the inertial profiler to measure the IRI, which is calculated based on the average IRI values from the right and left wheel paths [8].

The schematic diagram portrays the side profile of a vehicle carrying the inertial profiler. A height sensor was placed at the bottom of the vehicle to measure its distance to the road surface. At the top of the sensor, a small box was attached that acts as the accelerometer. Another sensor was attached to the wheel, and a computer inside the vehicle was connected to the sensors to accumulate the measured values [10]. The inertial profiler system typically consists of a distance-measuring instrument (DMI) to observe the distance along the roadway, an accelerometer to measure the movement of the vehicle frame, and noncontact sensors (lasers) to measure the relative displacement between the road surface and vehicle frame.

When evaluating the road surface, inertial profilers provide several significant benefits. They are renowned for having excellent precision and repeatability, guaranteeing accurate and consistent measurements. With the ability to gather data at highway speeds, high-speed inertial profilers can reduce testing-related traffic interruptions and lane closures. Furthermore, early-stage evaluations are made possible by employing lightweight inertial profilers on concrete surfaces that still need to develop more strength for regular traffic. They can be used in space-constrained construction zones because they only need a short lead-in distance to attain testing speeds [13].

The IRI, which measures road surface roughness by quantifying a vehicle's cumulative vertical displacement, remains a critical standard due to its widespread adoption and the availability of data across various regions [20].

C. *Related Studies*

Pavement surface roughness is a crucial indicator of drive quality and can create stress on the pavement structure that could cause premature pavement fatigue and hastened pavement deterioration. Indicators of pavement surface deformation include frequent pavement roughness indices and other pavement measurements. Highway safety is compromised by pavement distress, regardless of its source—it can come from below or above. Pavement drainage is also compromised. The pavement roughness index value deteriorates as a result of pavement distress. This implies that pavement roughness indices, such as the IRI, and the degree of pavement distress may be related [1].

IRI is the first smoothness index generally applicable to various pavement smoothness instrument types, and it is enhanced by a suite of software programs that compute the IRI value. In addition to being more effective, reasonable, and equitable than other smoothness evaluation indicators, the American Society for Testing and Materials (ASTM) has included it in its requirements. As a result, as Figure 3 illustrates, the IRI value may typically be used as an index to assess the smoothness quality [19].

Specifically, its linear properties allow it to be applied to identify pavement smoothness and objectively compare various smoothness levels. The IRI thresholds that are used globally, however, differ significantly. This is mainly because the following factors affect the IRI limit value: the kind of road surface, the road function category, the average annual daily flow (AADT), the legal speed limit, and the length of the road segment that is considered when calculating the IRI [6].

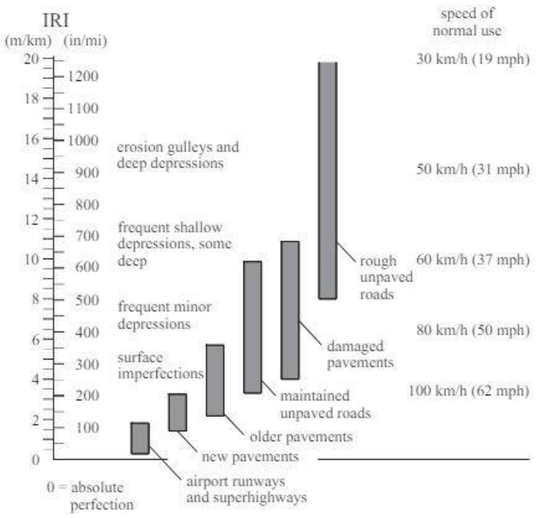

Fig. 3. Illustration of the IRI scale values on different pavements.

Gao et al. [11] explored the impact of seasonal traffic variations on road roughness, providing insights into how peak traffic periods exacerbate pavement wear. It highlights the need for traffic volume data integration in road maintenance strategies to predict and mitigate road degradation more effectively.

Perez-Acebo et al. [16] explored how high traffic volumes, especially from heavy vehicles, accelerate the deterioration of pavement surfaces, leading to increased IRI values. Their findings indicate that urban roads with high traffic density are susceptible to rapid degradation, necessitating more frequent maintenance and rehabilitation. Similarly, Siregar and Sumabrata [21] demonstrated that traffic volume is a significant predictor of road roughness, suggesting that effective traffic management strategies could mitigate some of the adverse effects on pavement conditions. These studies underline the importance of incorporating traffic data into pavement management systems to ensure accurate condition forecasting and timely interventions.

High IRI values, indicating poor road conditions, are associated with increased vehicle operating costs and higher risks of traffic accidents. Robbins and Tran [18] highlighted that rough roads lead to greater fuel consumption, vehicle damage, and tire wear, imposing additional costs on road users. Moreover, rough road conditions can compromise vehicle stability and control, increasing the likelihood of accidents [4]. These studies suggest that reducing IRI values through targeted maintenance can significantly enhance road safety and reduce economic burdens associated with vehicle damage and accident-related costs.

D. Theoretical Framework

This study uses the International Roughness Index (IRI), a standardized measure of road surface roughness, to maintain optimal road performance. It focuses on assessing road rehabilitation thresholds using the IRI in the urban context of Metro Manila. The IRI is a reliable metric for evaluating road conditions; road roughness directly impacts vehicle operating costs, ride quality, accident risk, and pavement lifespan.

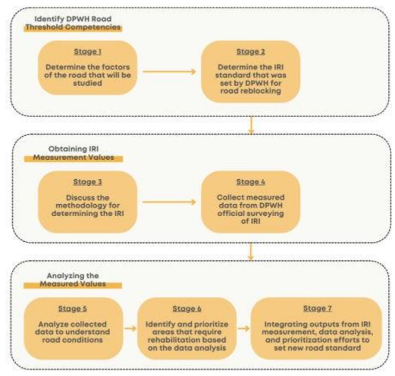

Fig. 4. Conceptual Framework.

The framework starts in part "Identifying DPWH Road Threshold Competencies," where the road variables to be examined are established. Stage 2 entails identifying the IRI standard for road reblocking specified by the Department of Public Works and Highways (DPWH). These preliminary steps are essential because they set the boundaries and standards for the later investigation.

Stage 3 of the second section, "Obtaining IRI Measurement Values," discusses the process for figuring out the IRI. This is a crucial stage since it guarantees the accuracy and standardization of the measurement procedure. The fourth stage is gathering measured data from the official IRI survey conducted by DPWH. This section guarantees the validity and reliability of the data that served as the basis for the analysis.

"Analyzing the Measured Values," the last phase, includes Stages 5, 6, and 7. Stage 5 involves analyzing the data gathered to comprehend road conditions. By ranking these locations according to the data analysis, Stage 6 addresses the places that require repair. This analysis aids in identifying these areas. In order to establish new road standards, Stage 7 also entails integrating the results of IRI measurement, data analysis, and prioritizing initiatives. With this all-encompassing strategy, rehabilitation operations are guaranteed to be data-driven, focused, and successful in enhancing road conditions, eventually improving urban mobility, increasing safety, and lowering vehicle operating expenses.

III. METHODOLOGY

A. Research Design

The International Roughness Index (IRI) will be the primary tool used in the study to assess road conditions over eight years in terms of quality. The Department of Public Works and Highways or other pertinent government entities are potential secondary sources from which the data collection, which consists of IRI values for different road segments in Metro Manila, will be gathered. Variables like the year of measurement, road segment identification, IRI values, segment length, and year will all be present in this historical data.

The study will apply various statistical instruments to assess the data gathered. Initially, descriptive statistics will provide a basic knowledge of how roughness levels have changed by summarizing the central tendency and dispersion of IRI values across various road lengths and years. After that, a time series analysis will be carried out to assess patterns over the eight years and ascertain whether road conditions are worsening or staying the same. This trend analysis will show the rate of change in IRI values, which can identify segments that are deteriorating more quickly. An ANOVA with repeated measures will be used to see whether there are any noteworthy variations in IRI values over time. These tests will account for the repeated nature of the data and will indicate whether changes in mean IRI values across the years are statistically significant.

B. Research Setting

The study centers on Roxas Boulevard and Aurora Boulevard, the two main thoroughfares in Metro Manila. These routes, which are all of great economic significance and heavy traffic volumes, are essential arteries in the city's transportation system. Stretching along Manila Bay, Roxas Boulevard is a popular tourist destination with several landmarks, business facilities, and a vital commuter route. However, it frequently sees excessive traffic. Aurora Boulevard is a significant east- west thoroughfare that links multiple metropolitan areas and facilitates commercial, industrial, and residential activity.

By focusing on these critical corridors, the study aims to capture a representative sample of urban road conditions, reflecting the challenges and complexities inherent in managing transportation infrastructure in a densely populated and extended road in the metropolitan area. Moreover, selecting these roads enables examining road conditions across different segments, allowing for comparative analysis and identifying areas requiring priority intervention and rehabilitation efforts.

C. Data Gathering Instruments

DPWH has stated that the instruments used to gather data for the IRI were a laser profilometer, distance measurement instrument, cameras, a global positioning system (GPS), and special laptop computers [22].

A laser profiler's primary function is to evaluate the state of road surfaces, especially their smoothness and roughness [5]. Transportation agencies and road authorities need this data to assess the condition of the roads, pinpoint locations that require repair or maintenance, and set infrastructure spending priorities. Furthermore, laser profilers are essential for quality control in road building and maintenance operations since they guarantee that freshly built or resurfaced roads adhere to strict smoothness guidelines.

It is possible to determine the change in the longitudinal profile of the identified road survey line using the trip distance measured with the distance measurement instrument (DMI). The data acquisition host mounted in the car receives direct signals from the displacement sensor, accelerometer, and DMI. The host sends the data to the notebook computer using a USB cable. The system can execute right-of-way photography integration and IRI calculations, analyze numerical outputs, and GPS positioning data using video cameras and GPS signal receivers (Chen, 2020). This system supports numerous GPS signal receivers and video cameras that capture road conditions and driving positions. Furthermore, calibration and validation testing verified the inertial profiler's functionality.

D. Equations

Finding any anomalies or incorrect entries in the IRI values requires data quality checks and outlier analysis to guarantee data accuracy and consistency. In order to identify odd deviations that can result from measurement errors or inconsistent data-gathering procedures, statistical approaches are used in this process. The Z-score approach is a frequently employed technique that standardizes the data to indicate that the number of standard deviations from a given IRI value deviates from the mean. This makes it simpler to identify values that are abnormally high or low. Corrective measures, such as eliminating or modifying these outliers, can be required based on the results to stop them from distorting the study and drawing the wrong conclusions.

For every year and road segment, a summary of the IRI data will be provided using descriptive statistics. The significant tendencies and variability in road roughness will be summarized by critical metrics, including mean, median, and standard deviation. The standard deviation will show the variation in conditions across various road sections, while the mean IRI value will show the average roughness for particular road segments or years. General trends and outlier segments with extreme roughness values that could be needed for quick intervention can be found with the aid of this preliminary study.

A histogram and cumulative percentage curve will be carried out to monitor the changes in IRI values throughout the eight years and identify the common levels of roughness and patterns in road deterioration. The curve will help in identifying what sections of the road have exceeded the IRI threshold. The curve will assist in defining the rehabilitation threshold necessary to be implemented by showing where roughness becomes critical.

To determine essential restoration thresholds, the study will perform a threshold analysis by comparing IRI levels against existing benchmarks, such as the DPWH guideline of a maximum IRI value of 3.00 m/km for newly constructed pavements. This analysis will identify the segments that must be addressed immediately since they surpass acceptable levels. By integrating these statistical tools, the research will provide a robust analysis of road roughness trends, facilitating the determination of ideal rehabilitation thresholds and directing efficient maintenance approaches for the urban road networks in Metro Manila.

IV. RESULTS AND DISCUSSION

A. Verification of Data Gathered

The local sector for transportation, Department of Public Works and Highways, has measured the local roads in Metro Manila due to the Department Order No. 48 (2019) since 2015. The IRI data in Table 1 was gathered through the means of the National Road Roughness Index Program (NRRIP), which is a government initiative that is dependent on public funding. The data was projected every two years due to the lack of funding by the local government, causing the international roughness index values to not be consistent. Some road sections weren't surveyed due to budget limitations, ongoing heavy traffic or construction. In addition, the irregularity of survey was from 2020 to 2022 due to the pandemic, COVID-19, thus resulting in a jump from 2019 to 2023.

TABLE I. GATHERED IRI VALUES FROM THE DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS.

Item	Road Name	Section ID	Length	2015	2017	2019	2023
1	*Aurora Boulevard*	S03337LZ	1108	0.00	0.00	5.85	0.00
2		S03355LZ	1105	0.00	0.00	3.72	0.00
3		S05605LZ	4076	0.00	0.00	3.53	0.00
4		S05606LZ	3150	4.23	4.19	4.61	4.75
5		S05607LZ	3170	3.64	4.19	3.92	3.84
6		S05608LZ	4078	0.00	0.00	4.38	0.00
7	**Roxas Boulevard**	S02725LZ	2847	0.00	0.00	2.45	0.00
8		S02784LZ	193	0.00	0.00	4.22	0.00
9		S02785LZ	210	0.00	0.00	4.25	0.00
10		S02883LZ	2852	0.00	0.00	2.85	0.00
11		S03228LZ	18	0.00	0.00	3.33	0.00
12		S03353LZ	1786	4.94	4.10	4.53	5.27
13		S03494LZ	1795	4.84	4.07	4.15	4.29
14		S04543LZ	389	5.74	5.63	5.11	5.37
15		S04544LZ	2415	0.00	0.00	2.35	0.00
16		S04541LZ	2440	0.00	0.00	2.45	0.00
17		S04542LZ	385	5.35	6.10	5.54	5.55
18		S02896LZ	2453	0.00	0.00	0.00	0.00
19		S03251LZ	2551	0.00	0.00	0.00	0.00
20		S03495LZ	489	0.00	0.00	0.00	0.00
21		S03341LZ	380	0.00	0.00	0.00	0.00
22		S02938LZ	423	0.00	0.00	3.45	0.00
23		S02939LZ	425	0.00	0.00	4.22	0.00
24		S02942LZ	411	0.00	0.00	3.68	0.00
25		S02943LZ	409	0.00	0.00	2.35	0.00

TABLE II. COMPUTED Z-SCORES FOR AURORA BOULEVARD

Road No.	Road Name	2015	2017	2019	2023
1	*Aurora Boulevard*	0.64	0.65	1.79	0.64
2		0.64	0.65	0.73	0.64
3		0.64	0.65	0.95	0.64
4		1.43	1.29	0.33	1.48
5		1.14	1.29	0.49	1.08
6		0.64	0.65	0.05	0.64

TABLE III. COMPUTED Z-SCORES FOR ROXAS BOULEVARD

Road No.	Road Name	2015	2017	2019	2023
7	**Roxas Boulevard**	0.50	0.49	0.25	0.50
8		0.50	0.49	0.75	0.50
9		0.50	0.49	0.76	0.50
10		0.50	0.49	0.02	0.50
11		0.50	0.49	0.25	0.50
12		1.75	1.44	0.92	1.94
13		1.71	1.42	0.71	1.49
14		2.12	2.15	1.25	1.99
15		0.50	0.49	0.30	0.50
16		0.50	0.49	0.25	0.50
17		1.94	2.38	1.49	2.07
18		0.50	0.49	1.62	0.50
19		0.50	0.49	1.62	0.50
20		0.50	0.49	1.62	0.50
21		0.50	0.49	1.62	0.50
22		0.50	0.49	0.31	0.50
23		0.50	0.49	0.75	0.50
24		0.50	0.49	0.44	0.50
25		0.50	0.49	0.30	0.50

Table 2 and 3 projects the corresponding Z-scores of the gathered IRI values from road items 1-25. The z-score was computed through the formula Z = X-; wherein X is the IRI value, *mu* as the mean or average of the road in a year, and lastly *sigma* as the standard deviation of the road in a year. These statistical parameters are found in Table 4 and 5. According to Mondal [14], if the score is found to be more or less than positive and negative three (3 < Z < -3), the data should be deemed to be further investigated or corrected. From the resulting scores in these tables, it is shown that the data gathered were true and correct.

B. Detection and Analysis of the IRI Value over the 8-years data

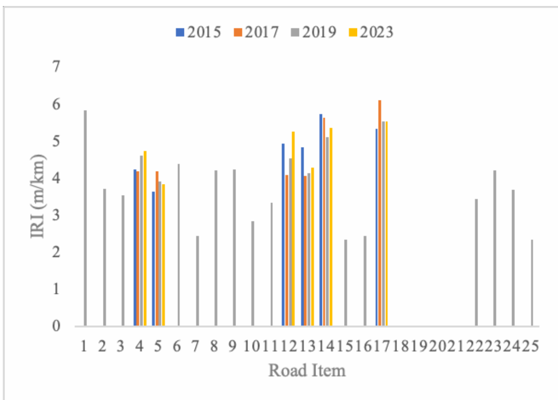

Fig. 5. Comparison of IRI Values in 8 years.

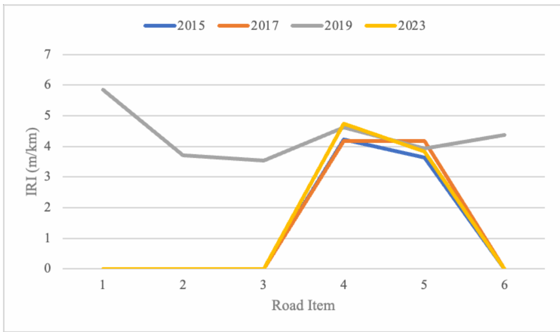

Fig. 6. Linear Trend of IRI Values in Aurora Boulevard

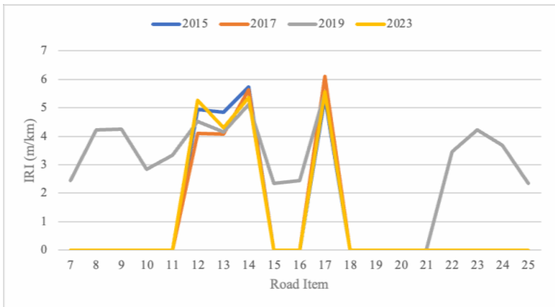

Fig. 7. Linear Trend of IRI Values in Roxas Boulevard

Figure 5 shows the IRI values of the 25 road sections during 2015 to 2023. It can be seen that only road items 4, 5, 12, 13, 14, and 17 are the only sections that were surveyed consistently. The IRI values across 2015 to 2023 generally vary between 3 and 6 m/km. Certain road items in Aurora Boulevard experience high values of IRI over time, indicating that a moderate to poor ride quality was experienced over the years. Some sections in Roxas Boulevard showed a similar pattern of road degradation where IRI values had increased, peaking in 2023, suggesting these roads experiencing wear and tear without sufficient rehabilitation.

Road items 3 to 5 showed improvement over the projected data as the value decreased, which signifies an appropriate rehabilitation was done, as shown in Figure 6. Meanwhile road items 11 to 14 and 17 signify a high amount of IRI which entails a poor ride quality, portrayed in Figure 7. Roads 4 and 12 show a clear trend of worsening road roughness by 2023. The overall trend projects a mixture of road deterioration and improvement across different road sections.

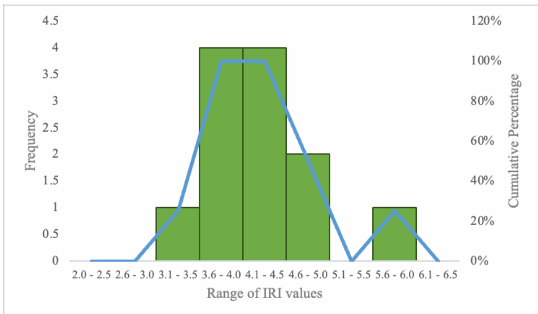

Fig. 8. Histogram and Cumulative Curve of IRI values in Aurora Boulevard

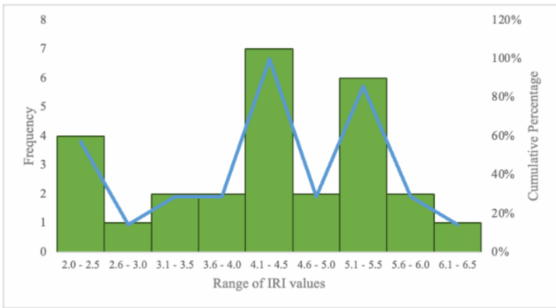

Fig. 9. Histogram and Cumulative Curve of IRI values in Roxas Boulevard

The most frequent value of IRI in Aurora Boulevard, Figure 8, is ranging between 3.6-4.5 m/km. Its peak frequency is occurring 4 times at 4.1-4.5 m/km, this suggests that roads in this range indicate moderate roughness of road condition. Approximately 80% of road sections in Aurora Boulevard have less than 5.0 m/km according to the cumulative percentage. The curve reaches 100% by the time it covers 6.1-6.5 m/km IRI value. On the other hand, Figure 9 shows that Roxas Boulevard has a broader spread of IRI values with no single range that is dominant. The highest frequency is in the 4.1-4.5 m/km range, with a frequency of 7 counts. Another significant peak is marked in the 5.1-5.5 m/km range. About 80% of the roads in Roxas Boulevard fall below the 5.5 m/km range, suggesting that most roads are in fair to moderately poor condition.

Both histograms show that the majority of roads fall in the moderate roughness category between 3.6-5.0 m/km. The histogram in Roxas Boulevard implies to be more heterogeneous as there is a wider spread of IRI values. About 20% of the roads have higher IRI values which suggests that a portion of the road network is in poor condition and requires immediate rehabilitation. Overall, it can be deduced that most of the road sections are in fair condition, with a small portion in need of effective repair.

C. Statistical Analysis of the IRI Value

TABLE IV. IRI VALUES IN AURORA BOULEVARD

Aurora Boulevard	
Statistical Parameters	2015 2017 2019 2023
Average Value (m/km)	1.31 1.40 4.34 1.43
Minimum Value (m/km)	3.64 4.19 3.53 3.84
Maximum Value (m/km)	4.23 4.19 5.85 4.75
Range (m/km)	0.59 0.00 2.32 0.91
Variance	3.47 3.90 0.60 4.17
Standard Deviation (m/km)	2.04 2.16 0.85 2.24

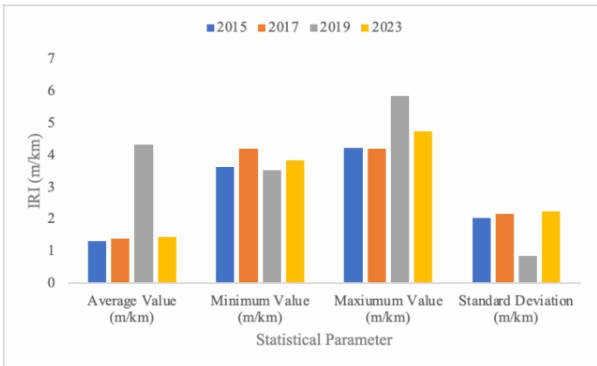

Fig. 10. Comparison of IRI values in Aurora Boulevard

TABLE V. IRI VALUES IN ROXAS BOULEVARD

Roxas Boulevard	
Statistical Parameters	2015 2017 2019 2023
Average Value (m/km)	1.10 1.05 2.89 1.08
Minimum Value (m/km)	4.84 4.07 2.35 4.29
Maximum Value (m/km)	5.74 6.10 5.54 5.55
Range (m/km)	0.90 2.03 3.19 1.26
Variance	4.55 4.29 3.01 4.41
Standard Deviation (m/km)	2.19 2.13 1.78 2.16

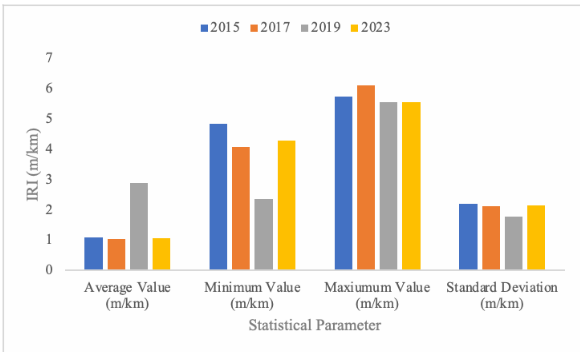

Fig. 11. Comparison of IRI values in Roxas Boulevard

The mean or average value of IRI of the surveyed roads is a single data point. The parameters such as the average, maximum, minimum, range, variance, and standard deviation values for the data were calculated and summarized in Table 4. The range was computed with the difference of maximum and minimum value per year in the data points. This computed value of range was used to identify whether the value IRI measured per year was good or bad. It can be seen from Figure 10 and 11 that the IRI's average value and standard deviation of the roads in Aurora and Roxas Boulevard has significantly improved from 2015 to 2019, but in 2023 the measured IRI has spiked high.

D. Figures and Tables

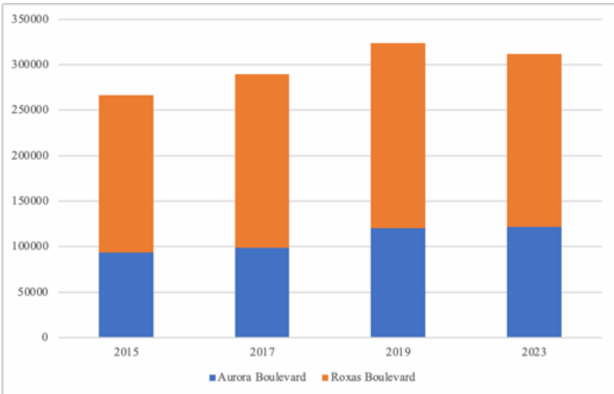

Fig. 12. Traffic Volume Data at Aurora and Roxas Boulevard

Both Aurora Boulevard and Roxas Boulevard exhibit significant traffic volumes from 2015 to 2023. The traffic flow seems to be rather consistent, with a minor uptick in 2019, especially on Roxas Boulevard. then dropping back to levels close to 2017 by 2023. Despite this traffic volume consistency, there is still a significant amount of traffic on the roadways, particularly on Roxas Boulevard, which has the largest volume of traffic in the dataset. Both Roxas Boulevard and Aurora Boulevard exhibit significant traffic volumes between 2015 and 2023, with Roxas Boulevard continuously seeing higher traffic loads than Aurora Boulevard.

Roads with large traffic volumes, such as Roxas Boulevard, may require more regular maintenance or lower IRI thresholds because of the correlation between traffic volume and IRI values, which indicates that these roads reach critical roughness thresholds more quickly. This link lends credence to the idea that traffic volume, a significant contributor to road deterioration, should be taken into consideration when setting thresholds for road restoration in Metro Manila rather than being applied consistently. To preserve smoother road conditions under high load, Roxas Boulevard, for example, would benefit from a more conservative IRI threshold, requiring intervention at a lower IRI compared to roads with lighter traffic.

Setting suitable IRI criteria and giving high-traffic road maintenance top priority can help reduce the economic losses over time. The city can increase Metro Manila's overall economic productivity, lower vehicle operating costs, and improve transportation efficiency by proactively maintaining road infrastructure to handle heavy traffic. By reducing the cost burden of road deterioration, this strategy emphasizes the significance of targeted infrastructure investment in maintaining urban economic growth and enhancing the quality of life for inhabitants.

E. *Inspection on the Appropriateness of IRI Threshold Values*

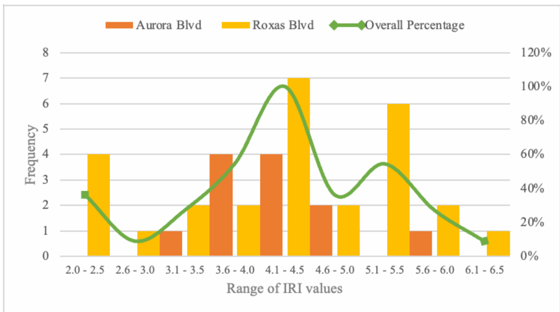

Fig. 13. Overall Histogram and Cumulative Curve of IRI values

Global standards such as the International Roughness Index have pushed many countries to establish IRI thresholds for road maintenance and rehabilitation scheduling. The Philippines' current acceptable pavement smoothness standards should not be more than 3.0 m/km for both concrete and asphalt.

As of this writing, the Philippines has not yet set an acceptable standard for road rehabilitation and scheduling. Among the 25 surveyed sections, both Aurora and Roxas Boulevard had 10 sections measuring an IRI value less than 4.6 m/km. From Figure 12, it can be seen that the curve peaked at the ranges of 4.1-4.5 m/km. The IRI thresholds used around the world are different as it all depends on the season, traffic volume, and other factors.

An IRI less than 3.0 m/km is considered to have a *good* pavement condition; an IRI between 3 and 5 m/km is rated as *fair* roughness condition; and a value greater than 5 m/km is considered to be a *poor* road condition. The overall histogram of the measured IRI distribution of the 25 asphalt road sections are shown in Figure 12. Based on Figure 12, the overall cumulative percentage of IRI values in both Aurora and Roxas Boulevard can be calculated. The figure shows that the curve of the values vary from the described intervals or range, although mainly distributed to 3.6-5.5 m/km. From the figure, it can be factored that the critical point of the range is at the peak, which is 4.1-4.5 m/km. Based on these results, it is recommended that the IRI threshold value for road rehabilitation in Metro Manila be set at 4.5 m/km. This value represents the point where roughness results in more frequency and the road quality deteriorates significantly, making it a reasonable threshold to intervene before the conditions worsen further.

V. CONCLUSIONS AND RECOMMENDATIONS

A. *Conclusions*

The study identified the longitudinal profiles of pavements in Aurora Boulevard and Roxas Boulevard and investigated the threshold values of acceptance of IRI in order to ascertain if the threshold is necessary to modify or retain for the maintenance scheduling of pavements. The results of analysis done allows for the derivation of the following conclusions:

1. The IRI value in Aurora Boulevard and Roxas Boulevard was mainly distributed between 3.6-4.5 m/km. The histograms projected that most of the road sections are in fair condition, with a small portion in need of effective repair.
2. According to the overall histogram from the surveyed 25 road sections, the cumulative percentage curve peaked at 4.1 to 4.5 m/km. Accordingly, it is recommended to set the IRI threshold for road rehabilitation in Metro Manila to 4.5 m/km. This threshold is more than the acceptable pavement smoothness set by DPWH, which makes it reasonable to set the threshold at this value.
3. The distribution curve of IRI values can estimate and determine the urgency of maintenance it needs before and after the slope of the critical point which will help estimate the budget that must be needed in the project.
4. The link between traffic volume and IRI supports the notion that, rather than being applied uniformly, traffic volume—a major cause of road deterioration—should be taken into account when establishing thresholds for road restoration in Metro Manila.

B. *Recommendations*

The analyzed data of IRI data from both Aurora and Roxas Boulevard recommends that the road rehabilitation prioritize the sections wherein the values of IRI exceeds 4.50 m/km. This value marks the critical point where the condition of the pavement significantly declines which leads to poor ride quality, more expensive vehicle operating cost, and worsened safety risks. Implementing rehabilitation measures before the IRI values reach more than the recommended standard can help the city minimize financial and operational burdens.

In addition, it is recommended for future researchers to include traffic volume data into the analysis to refine the threshold. Continuously monitoring the IRI values across the pavements in the city will enable urban planners to embrace a proactive strategy of maintenance. This approach will enable long-term sustainability, aligning with environmental goals and efficiently using the resources keeping Metro Manila's road structures to be resilient.

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