Methods on Calculating the International Roughness Index: A Literature Review

Juland A. Padilla and Orlean G. dela Cruz

Abstract The pavement management system determines the optimum maintenance techniques for each mile of the highway network. The total irregularities in the pavement surface per linear travel unit distance affect the ride quality. As a result, the safety of road users is known as pavement roughness or roughness index. The research aims to discover the various methods and procedures for computing IRI. It also wants to investigate how IRI affects the driver, the vehicle, and road conditions. The connection between road condition, roughness, and quality can impact the IRI values. Finally, considerations to various challenges and recommendations are in the proposal for evaluating IRI.

Keywords International Roughness Index · Pavement management system · Road conditions · Road roughness · Sensor-based monitoring system

1 Introduction

Highway structure should guarantee safe driving, the thoroughfare geometric design must be appropriate, and supporting facilities and management standards should be comparable [1]. Creating a pavement management system (PMS) determines the best maintenance strategies for each mile of the highway network. PMS uses pavement roughness measurement at the network and project levels [2, 3].

Pavement roughness is the sum of imperfections in the roadway surface per linear travel unit distance that degrade the ride quality of an automobile and, as a result, the safety of road users [3]. The assessment of the metrics for pavement roughness as ride quality determines the state of the pavement [4]. One of the specific measures is the International Roughness Index (IRI). The World Bank created IRI in the 1980s

J. A. Padilla
Civil Engineering Department, Technological Institute of the Philippines, Quezon City, Philippines
e-mail: japadilla.ce@tip.edu.ph

J. A. Padilla · O. G. dela Cruz (✉)
Graduate School, Polytechnic University of the Philippines, Manila, Philippines
e-mail: ogdelacruz@pup.edu.ph

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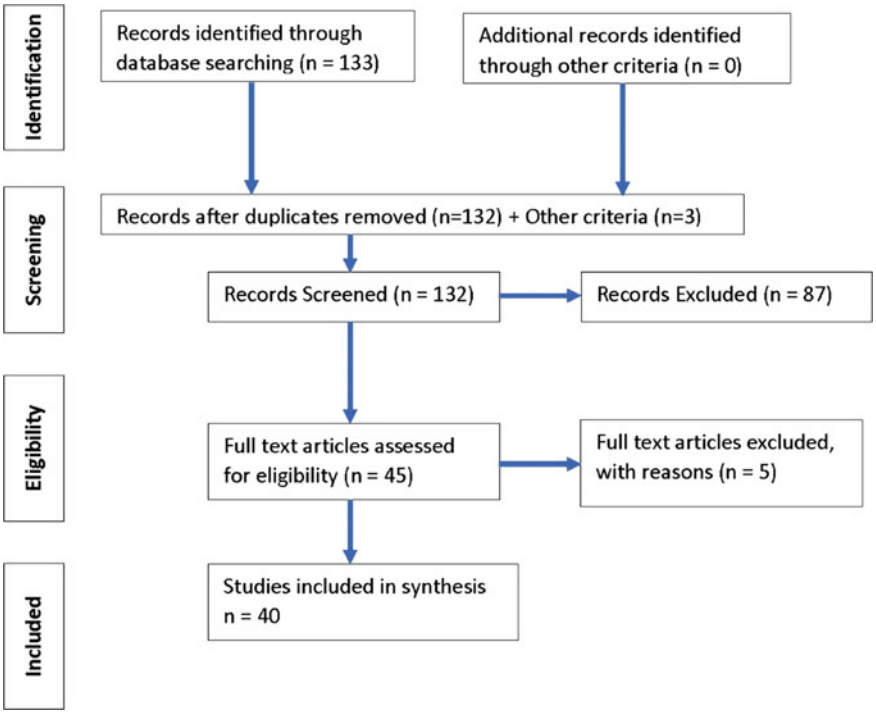

Fig. 1 Methodology of selecting past articles

for consistent infrastructure appraisal in emerging nations [5]. For highway maintenance and maintaining the safety and comfortability of road users or minimizing the dynamic load of cars and pavement, a precise characterization of the road roughness of longitudinal highway profile is required [6].

IRI claims that road surface roughness is generally acknowledged and used by road management authorities worldwide [7]. Moreover, IRI evolved from its establishment and renovated itself to cope with national needs. The study aims to determine the different methods and approaches in calculating IRI, connecting various aspects and observing some included or excluded factors for calculating IRI.

2 Methodology

This literature study aims to find empirical research examining the impacts and methods of calculating International Roughness Index values. To obtain topics to be discussed in the following, a comprehensive literature analysis to present data collecting using keywords such as the International Roughness Index. Scopus is one of the most widely utilized academic and practitioner journals search engines.

Using the Title/Abstract/Keyword in the database to search. One hundred thirty-three journals are selected and undergo screening to obtain four topics.

The Fig. 1 shows the selection process of past articles to create four topics.

3 Discussion

3.1 Methods in Getting IRI Values

The international roughness index (IRI) is a tool to identify the state of pavement degradation. The IRI value grows as pavement age increases [8]. The degree of surface roughness is one of the key factors supporting pavement degradation [9]. IRI computation system transforms longitudinal and vertical profile data into a vehicle motion response [10]. The road profile is measured using the dynamic response of cars and then simulated using the so-called quarter car method in which IRI is used in several countries [11] (Table 1).

3.1.1 Conventional Approach in Getting IRI Values

Data gathering is an essential element of the pavement control system's execution. Using automated systems to track vast road networks is accurate and saves time [1]. The Kinect depth data was validated and adjusted as the initial stage in this investigation. Using the ASTM E1926 method, the section has computed IRI value was determined logically and engineeringly by field observation and expert knowledge. It was also verified using a precise manual device [20].

Table 1 The approach of getting IRI Values

Study	Methods of getting IRI	Standard	Modern
[8, 12]	GMDH and ANN method	x	
[10, 11]	Quarter Car Model	x	
[1]	Road Roughness Monitoring	x	
[4]	Real-Time Fitness Analysis		x
[3, 13, 14]	Use of accelerometer of a smartphone		x
[15–17]	Using roadroid on a smartphone		x
[18]	Inverse Pseudo Excitation Method	x	
[19]	Physiological Pavement Evaluation	x	
[20]	Use of a Low-Cost Sensor	x	
[21, 22]	Using Regression Analysis	x	
[23]	Vehicle suspension car model	x	

Another IRI calculation is the Inverse Pseudo Excitation Method (IPEM). Experimented with speed, road roughness rating, type of vehicle, and tire enveloping characteristics influenced the new strategy [18]. In addition, regression analysis based on applying the theory of jerk equation can evaluate road roughness wherein jerk is the result of the sudden change in acceleration which affects riders comfortability [22]. Moreover, conducting a preliminary study of the physiological assessment of pavement roughness showed the influence of road roughness on passenger safety and comfortability [19].

3.1.2 Modern Approach in Getting IRI Values

A smartphone app can test real-time bitumen road and vehicle performance [4]. It found out that FFS and V50 have a significant association with road roughness. Furthermore, calibration of the road-induced acceleration values to produce the PSD of research paths using phones. Moreover, Mathlab Code investigates the relationship between the square root of the PSD of raw acceleration values and average IRI values [13]. In most cases, increasing IRI value decreases speed rapidly [14]. Under natural driving conditions, vehicle vibration response can be a robust measure of pavement roughness [3].

3.2 IRI and Safety

Road surface degradation and deterioration in road safety are of particular concern. [23]. Recent evidence shows the association between pavement roughness and life use in road surface management. The established International Roughness Index is indirectly proportional to the vehicle's prescribed safe speed [7]. Using the path M&R cost constraint index, the calculation for safety enhancement satisfies the limits on preservation and rehabilitation costs by applying the Floating Fixed-length Segmentation procedure to the chosen highway [24]. For freight transport, well-maintained roads are essential since they help reduce vehicle and cargo damage during transportation [25].

The Dynamic Load Coefficient determines the relationship of IRI to the safety of ride quality [6]. A real-world vehicle trial established the linear correlation between IRI and the driving workload. Aside from affecting ride quality and comfort, road surface roughness on the theory and calculation of driving workload and the comfort and safety threshold [26]. The safety results are relevant: drivers pay less attention to secondary triggers as the IRI rises [27]. The development of four safety efficiency functions to collect data on the safety implications of IRI-measured pavement surface roughness. The measurement uses single-vehicle accidents to develop the four safety efficiency aspects in a complete, rear-end, same-direction sideswipe [28].

3.3 IRI as Road Quality Indicator

The evaluation of road conditions is crucial in determining the extent of road injury [15]. To prioritize road maintenance, IRI is a commonly used parameter for quantifying road roughness and identifying the level of degradation for all roads. A low IRI value indicates a smooth lane, while a high value indicates a distressed road [29]. Prof. Vasilyev developed a dynamic approach for estimating highway maintenance efficiency that allows for a comprehensive and reasonable evaluation of road maintenance [30]. Various tools such as the Profilograph, Response-Type instruments, Walking Profilers, and Inertial Laser Profilers are available to test IRI [16].

Permanent deformation is a significant load-related discomfort in flexible pavement structures and worsens with load repetitions, impacting road roughness, serviceability, and the international roughness index (IRI) [31]. Roadroid tools extract IRI values by pairing SDI values to determine appropriate maintenance recommendations [17]. Because of the non-stationary nature of real road profiles, they vary significantly from artificial ones. Appropriate in situ measurements are needed to determine road pavement roughness and user impact [32]. Although certain distresses have a little discernible effect on maps, the a_{wz} method identifies essential parts for proper assessments and surveys that determine the distresses' causes to choose suitable maintenance measures [33].

A customer-oriented level of service is putting more pressure on high-quality road management. Obtaining roughness data in road networks for running PMS and using the IRI to assess public roads in local cities is essential for road administrators. STAMPER has profited substantially by permitting the computation of real-time road surface profiles without the need for a specific vehicle. It is also feasible to simultaneously collect road profiles for both wheel directions and IRI and acceleration measurements [34]. However, expansive soils will hasten pavements' degradation, resulting in increased cracking and roughness [35].

3.4 Effects of IRI in Road Conditions

Representing roughness indices in recent decades to signify pavement surface characteristics and relative performance [2]. Roughness on urban roadways is impacted heavily by the terrain's natural topography elements and features [36]. IRI and crash rate have a unique connection in all circumstances, suggesting that crash rate does not essentially rise to a particular IRI number [37]. Due to the vicious loop formed between the mutually aggravated roughness and the increase in dynamic vehicles/pavement contact forces, the growth in pavement roughness and its degradation increases in a non-linear manner [38]. The IRI measures the functional performance of road pavements and acts as a structural performance indicator [39]. However, measurement variability can affect IRI determinations by calculating the IRI value of a road segment on a single test run [40, 41]. Preliminary vehicle response/fatigue

damage estimates require a thorough grasp of the road profile and its objective roughness categorization. The use of IRI and Power Spectral Density (PSD) to objectively classify a road's severity [5].

4 Challenges and Gaps

The IRI has become commonly used as a roughness index indicator for analyzing and maintaining road networks [5]. Based on the study, the relationship of road condition, roughness, and quality can affect the outcomes of the values generated for IRI [5, 11, 34, 37–39]. Hence, the load applied to each road specification is due to road and vehicle conditions disputes such as damaged roads [4, 14, 24, 26, 35]. Moreover, even a slight change in vehicle speed and vehicles can also affect the values [2, 3, 7, 15, 19, 28, 29, 33]. Both parts are likely to be evaluated as fair erroneously due to measurement uncertainty [39] given the many variables that influence road pavement roughness and evaluation, the utility of generated fake profiles for analyzing specific parameters and evaluating their effects on ride quality [27, 32, 41].

Although some research shows great promise and can disrupt specific established approaches, there is still space for improvement [1, 8, 18, 25, 34]. Even the versatility of the smartphone-based roughness assessment approach opens a world of options for improving pavement management decision-making. However, it may vary on the models used during the experiment [13, 16, 17]. Hence, errors in measurement procedures are unavoidable. These mistakes frequently add to the anticipated value modeling error, increasing the total error [8, 10, 23, 30, 31]. For any reason, the suggested approach for reconstructing a 3D model of a pavement surface is time-consuming and computationally intensive [20] (Table 2).

Table 2 Challenges considered in IRI Evaluation

Citation	Challenges
[5, 11, 34, 37–39]	Relationship of Road roughness, ride quality and road condition
[2, 3, 7, 15, 19, 28, 29, 33]	Type of Vehicle and Speed
[6, 25]	Road roughness measurement using a sensor-based monitoring system
[13, 16, 17]	Data collected varies on the cell phone model, vehicle, and speed
[4, 14, 24, 26, 35]	Road Condition
[8, 10, 23, 30, 31]	Creating another method to satisfy the result
[1, 8, 18, 25, 34]	Further analysis of other factors that may affect the result
[27, 32, 41]	Parameters Considered
[20]	Time-consuming in generating 3D model

When selecting road sections, the following characteristics may lead to horizontal bends with a minimum radius of 130 m. More damage roads to minimize and eradicate any impact on automobiles applying brakes at curves (60 km/h). Even minor changes in vehicle speed and vehicle type might impact the results. The International Roughness Index (IRI) calculation can vary in several ways. Some nations may even change these indexes to meet their national requirements while maintaining the universal idea. It is necessary to demonstrate that road conditions, such as degradation and driving behavior, can aid future studies.

5 Conclusions

Since 1980, the International Roughness Index (IRI) has a variety of calculation methods. The conventional and modern approach introduces many equations, methodologies, or techniques to prove the roughness index's accuracy. Some countries may even modify these indices to cope with their national standards while anchoring its principle to the international. However, some parameters and event data may be restricted during experiments to produce an outcome; moreover, it excludes some factors that may affect IRI results. The summary of the past research focuses on the systemic and empirical approach for calculating IRI. Hence, it is needed to show that road conditions, such as deterioration and drivers' behavior, may contribute to future research as it dives more profound into the analysis. Some research also recommends the consideration of other indices as to IRI. Moreover, further developments for the equipment's utilization for future study may also enhance the present equipment and modify it to accommodate the other factors.

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